REPORT OF SURVEY

SAN GABRIEL & SANTA ANA RIVER WATERSHEDS

CALIFORNIA

For Runoff and Waterflow Retardation and Soil Erosion Prevention

U. S. DEPARTMENT OF AGRICULTURE

UNITED STATES DEPARTMENT OF AGRICULTURE

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Pursuant to the Act of June 22, 1936 (49 Stat. 1570)
as Amended and Supplemented

July 1952

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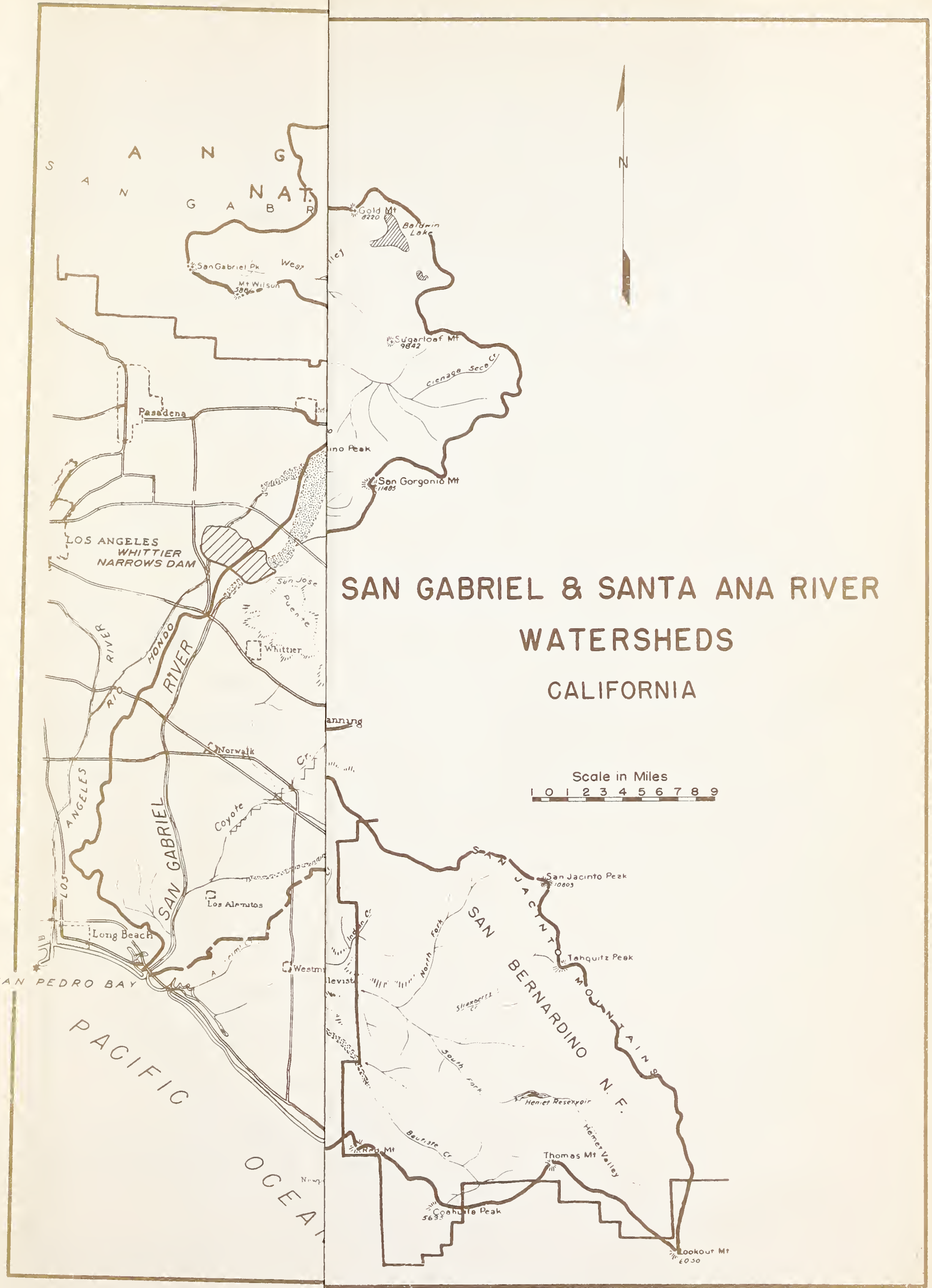
SAN GABRIEL & SANTA ANA RIVER
WATERSHEDS
CALIFORNIA
Scale in Miles
1 0 1 2 3 4 5 6 7 8 9
N
Gold Mt
8220
Baldwin Lake
San Gabriel Pk
Mt Wilson
Sugarloaf Mt
9842
Cienaga Seca Cr
Pasadena
San Gorgonio Mt
11485
LOS ANGELES
WHITTIER
NARROWS DAM
San Jose
Puente
Whittier
RIO HONDO
RIVER
SAN GABRIEL
LOS ANGELES
Norwalk
Coyote
Los Alamitos
Long Beach
SAN PEDRO BAY
PACIFIC
OCEAN
Westm
San Jacinto Peak
10805
SAN JACINTO MOUNTAINS
Tahquitz Peak
SAN BERNARDINO N. F.
North Fork
South Fork
Hemet Reservoir
Hemet Valley
Bautista Cr
Thomas Mt
Coahuila Peak
Lookout Mt
6050

O.H.D 6-13-31


SAN GABRIEL & SANTA ANA RIVER
WATERSHEDS
CALIFORNIA
Scale in Miles
0 1 2 3 4 5 6 7 8 9
N
LEGEND
Watershed Boundary
Boundary between San Gabriel and Santa Ana Rivers.
County Boundary
National Forest Boundary
ANGELES NAT. FOR.
SAN GABRIEL MOUNTAINS
SAN BERNARDINO N.F.
SAN BERNARDINO MOUNTAINS
SAN JACINTO MOUNTAINS
SAN BERNARDINO N.F.
CLEVELAND N.F.
SAN GABRIEL DAM NO. 2
SAN GABRIEL DAM NO. 1
SANTA FE DAM
LOS ANGELES WHITTIER NARROWS DAM
PRADO DAM
SAN GABRIEL RIVER
SANTA ANA RIVER
RIO HONDO RIVER
LOS ANGELES
PACIFIC OCEAN
SAN PEDRO BAY
LOS ANGELES CO.
ORANGE CO.
SAN BERNARDINO CO.
RIVERSIDE CO.
SAN BERNARDINO
RIVERSIDE
SANTA ANA
Pasadena
Claremont
Pomona
Ontario
Chino
Corona
Colton
Redlands
Beaumont
Banning
Anaheim
Fullerton
Norwalk
Whittier
Long Beach
Tustin
Orange
Hemet
San Jacinto
Perris
Elsinore Lake
Wildomar
Railroad Can. Dam
Lakeview
Winchester
Moreno
Alessandro
Highlands
Patton
Cucamonga
Rialto
Covina
Lemon
Garden Grove
Westminster
Fairview
Los Alamitos
Carbon Cap Dam
Fullerton Dam
Live Oak Dam
San Dimas Dam
Big Dalton Dam
San Antonio
Pine Mt
Seven Oaks
San Bernardino Peak
San Gorgonio Mt
San Jacinto Peak
Tahquitz Peak
Thomas Mt
Lookout Mt
Valle Vista

AUTHORITY

This report is submitted under the provisions of Section 6 of the Act of June 22, 1936 (49 Stat. 1570), as amended and supplemented by the Act of June 28, 1938 (52 Stat. 1215).

PURPOSE AND SCOPE

This survey investigated the floodwater and sediment damage problems to determine the needed remedial measures on the San Gabriel and Santa Ana River watersheds and to present recommendations for a program of runoff and waterflow retardation and soil erosion prevention.

RECOMMENDATIONS

The investigation was made to determine flood causes and measures necessary to effect runoff and waterflow retardation and soil erosion prevention. It revealed that unstable mountain headwaters and present use of wild and agricultural land add to the serious sedimentation and flood damage in the basin. The investigation finds that intensification, acceleration, and adaptation of certain activities under current programs of the Department and additional measures not now regularly carried out in such programs will be necessary for a balanced runoff and waterflow retardation and erosion-control program for the watershed basin.

The measures necessary for such a balanced program, in addition to those now carried on by the Department of Agriculture, are:

1. Intensification of fire prevention and control activities on about 1,025,300 acres of hazardous wild lands.

2. Vegetative and structural stabilization of about 135 acres of eroding road fill slopes and the improvement of road drainage facilities on about 200 miles of roads.

500?

3. Improvement of about 520 miles of community waterways in the lower basin.

4. Construction of terraces on about 40,600 acres of hay and grain land.

5. Construction of farm runoff disposal systems on about 97,000 acres of citrus, deciduous orchard, and vineyard land.

6. Cover improvement on about 196,000 acres of range land including stockwater developments and fences.

7. Seeding about 14,800 acres of steep eroding grain land. what

direct aids

Technical assistance, and educational services will be supplied for planning and applying the necessary land-use adjustments, for the planning and applying of conservation measures on the watershed, and for integrating these measures with the other measures included in the recommended program.

It is recommended that the Secretary be authorized to carry out this program. The extent to which the work recommended in this program is to be carried out under authority of the Flood Control Act as requested herein or under other authorities will be considered by the Secretary in requesting appropriations for the conduct of the recommended program. Although the current activities of the Department primarily related to the Flood Control Act are not included in the program herein specifically recommended, this program is based on the continuation of such current activities at least at their present level. The extent to which the measures in the recommended program may be carried out by an increase in the current programs of the Department will be taken into account in requests for the appropriation of funds to carry out the recommended program.

Further, the Secretary of Agriculture may construct such buildings and other improvements as are needed to carry out the measures included in the recommended program.

Based on 1946-47 prices, the total installation cost of this recommended program is estimated to be $32,556,500, and the cost to the Federal Government is about $24,890,100. Of the operation, maintenance, and replacement cost of $927,500, the Federal Government is to contribute $332,800.

The estimated average annual cost of this program is $1,916,900, and the estimated benefits are $2,361,900. 1/ In addition, there will be benefits that cannot be expressed in monetary terms.

The ratio of the average annual benefits to the average annual costs is 1.23 to 1.0. 1/

It is believed that only through the measures and practices recommended for the watershed can full beneficial waterflow retardation and soil erosion prevention be achieved. However, the Secretary of Agriculture may make such modifications or substitutions of the measures described herein as may be deemed advisable due to changed physical or economic conditions or improved techniques whenever he determines that such action will be in furtherance of the objective of the recommended program.

Furthermore, the Secretary may modify existing restrictions relative to use and development of wild areas in order to permit treatment of floodwater and sediment sources within the wild areas.

1/ Comparison of benefits and costs based on projected price and cost levels assumed to prevail under a full level of employment. For discounting purposes Federal and other public costs were figured at 2-1/2 percent interest and private costs at 4 percent interest.

It is anticipated that the recommended measures for non-Federal land will be installed, and operated and maintained under cooperative arrangements with agencies acceptable to the Secretary of Agriculture.

The authority of the Secretary of Agriculture to prosecute the recommended program shall be supplemental to all other authority vested in him by law to carry out any of the measures described herein or any other measures that are similar or related to the measures described herein.

It is recommended that the Congress authorize this plan to be carried out in its entirety or portions thereof at such time as public demand requests.

DESCRIPTION OF THE WATERSHED

The San Gabriel and Santa Ana River watersheds, contiguous watersheds, embrace an area of 3,183 square miles (2,037,000 acres) lying principally in Los Angeles, San Bernardino, and Riverside Counties, and partly in Orange County in southwestern California. Map 1 shows the location and general outline of the watershed. The two rivers enter the Pacific Ocean at points less than 15 miles apart. The drainage area of the San Gabriel is elongated and irregular, its northern third comprising a portion of the great mass of the San Gabriel Mountains, and its southern two-thirds a gently sloping valley floor interrupted midway to the ocean by low folded formations of the South, San Jose, Puente, and Coyote Hills.

The adjoining Santa Ana basin is dominated on the north and east by the San Gabriel, San Bernardino, and San Jacinto Mountains, which rise abruptly from the coastal plain. These mountains are characterized by rough terrain, narrow deep canyons, and steep channel gradients. Elevations range from 1,700 feet at the base of the mountains to more than

11,000 feet at the summit of San Gorgonio Peak.

Geologically, both watersheds are young. The mountain block, occupying about 47 percent of the watershed, has been carved by streams into an intricate pattern of deep, V-shaped canyons and sharp, narrow ridges. Throughout the period of mountain building the rock mass has been intensively faulted and fractured. Geologic development coupled with the effects of repeated fires and extensive road building has produced a relatively unstable mountain mass yielding extremely high rates of erosion. As a result of the deeply fractured rock mass of the mountains considerable capacity for the reception and temporary storage of water exists. Rain water percolating through the soil and entering the numerous cracks and crevices in the shattered rock gradually works down to a point of release which may be a spring in a canyon or some subterranean point along the mountain front deep under the valley fill.

Deep fracturing of the rock has also increased its capacity for receiving and storing water, an extremely important function since the shallow soil alone has rather limited storage capacity. One of the greatest functions of the mountain mass is to serve as a natural catchment and water storage reservoir.

The canyon-carving process was accompanied by the deposition of vast quantities of eroded material near the canyon mouths where the extensive debris cones now fan out into the valleys. Geologic erosional processes made available the material which through the ages filled the deep alluvial valley plain.

The soils of the mountain slopes are a residual product of rock weathering and plant development. They vary from very immature, rocky

soils to fine, sandy loams, ranging in depth from less than a foot to as much as eight feet. Under the protective influence of a good plant cover the mountain soils are capable of high permeability, and are relatively stable.

The valley and plain areas, characterized by agricultural and suburban developments, are extensive alluvial plains interrupted by low sedimentary hills. Forty-three towns with population of 200 to 55,000 intersperse the agricultural lands which are used for growing citrus, avocados, diverse crops, and livestock. Almost half of the valley soils are highly pervious recent alluvium, normally a low producer of silt. The benchland and upper valley soils are loose and friable with highly developed impervious subsoils. Infiltration is low but erodibility is very high. These soils occupy about 20 percent of the valley area. The residual soils of the rolling hills have a low infiltration rate, high erodibility, and are particularly susceptible to landslides.

The equable climate of the south coastal section of California is in large part responsible for the extensive urban and suburban community development which has intensified the flood problem. Intensive, year-long subtropical agriculture, made possible by the mild winters, is now practiced on about 40 percent of the area. Agriculture is gradually being crowded by the expanding industrial and residential development, particularly in the western side of the basin.

Annual precipitation varies from 10 inches in the coastal plain to almost 45 inches in the headwaters. Some snowfall occurs in the high mountains but snow melt is considered to have little influence on the flood flows of the main drainage system. The short winter season is characterized

by storms which occur almost entirely during the four-month period between December and March with short periods of intense rainfall that frequently culminate in damaging flood flows.

FLOOD PROBLEMS

Past Floods.--Since 1811, twenty-one large floods have been reported in the San Gabriel River basin. The most important of these were the floods of 1815, 1825, 1862, 1868, 1876, 1884, 1891, 1916, 1927, 1934, 1938, and 1943. In the Santa Ana basin five great floods have been recorded since 1811. They occurred in 1825, 1862, 1867, 1891, and 1938.

During this period the Los Angeles, San Gabriel, and Santa Ana Rivers each changed its course at least once. Of these three rivers the San Gabriel has been the most unstable, shifting from one side of the valley to the other during its history. This shifting has been caused by the deposit of large amounts of debris from the mountain watersheds in the valley channels.

Accurate records of flood damage are not available prior to 1938. The Corps of Engineers made the first comprehensive damage survey of the flood of February 27 to March 4, 1938, which caused great damage along the main rivers and their tributaries.

Floodwater and Sediment Sources.--The principal flood sources can be segregated into two broad areas--the mountainous wildlands and the agricultural areas of the valley and lower foothills.

The natural geologic instability of the extensive mountain region coupled with a century of intensive and unhampered use is reflected in the abnormally high rates of erosion in these two basins. Repeated burns in the wildland area have intensified erosion until almost every tributary drainage shows some effect of this man-caused source. Stream beds have been

scoured and unsupported channel side slopes have gullied and slipped to rejuvenate erosion on whole mountain sides. Stream channels have been refilled with debris ranging in size from huge boulders to fine sand. Fire has been only one destructive agent responsible for accelerating an already tremendous erosion rate. Mountain road construction has altered the hydrologic characteristics of entire watersheds by creating erodible fill and overcast slopes, and uncontrolled surface drainage. Uncontrolled mountain streams continue to undercut steep unstable side slopes which feed large quantities of soil and rock into the channels for transport downstream. All of these factors contribute to maintaining the instability of active source areas in the mountains. Consequently, the sedimentation rate continues high, ranging from 1,400 to 9,800 cubic yards per square mile per year at and below the canyon mouths.

Erosion and deposition rates are influenced not only by the condition of the plant cover but also by the cyclic character of the storms common to this area. Consequently, these processes do not occur in a uniformly contínous manner but alternate in intensity between the relatively dry periods and the flood periods. The interval between these periods varies from a very few years to as many as ten years. During the relatively "dry" periods, the waste mantle of weathered material slowly creeps downhill into the small tributary channels, gradually reducing the capacity of the small waterways. The rate of movement from the slope being dependent upon the density of the plant cover and its ability to bind the soil or rock waste mantle. This slow downhill movement and gradual channel aggradation proceeds until in the minor tributaries, the high water of wet winters moves the accumulated material out of the steep side channels into the larger canyons. This process occurs over and over until a major flood-producing storm scours out

the main channels, transporting the accumulated bed load downstream and out into the valley. During major floods the lower main channels discharge vast quantities of this eroded debris, yet at the same time additional quantities are deposited in all the lower reaches by discharging headwater tributaries.

Erosion on the agricultural lands is widespread. Soils of the sloping cultivated lands are practically all affected by water erosion unless protected. The most extensive areas of serious water erosion are in the dry-farm grain sections where several thousand acres have been forced into abandonment because of loss of top soil.

Along the San Bernardino mountain front, streams from the mountains, carrying large quantities of sediment, form a braided distributing system of constantly shifting washes on the alluvial valley slopes where intensive agricultural developments are located. In the San Timoteo Creek watershed, for example, the main drainage system is entrenched in old and recent valley fill material except in the lower reach near the Santa Ana River. The valley stream system and contributing agricultural lands are active sources of sediment from both gully and sheet erosion.

The frontal area of the San Gabriel Mountains, particularly its steep slopes partially stabilized by the natural plant cover, is a potentially high debris and floodwater source. The intensely developed alluvial fans and valley areas immediately below the mountain front are in constant danger of floods. In recent years partial protection has been provided by numerous flood-control and water-conservation reservoirs, debris basins, and improved channels. Many of these costly structures must be constantly maintained after every intense storm because of the high sedimentation rates and the constant threat to the developed valley area should a major

flood occur when the basins are only partially filled with debris and sediment. The accumulation of debris behind other structures and in the channels poses major engineering problems of eventual sediment removal, abandonment of some structures, or a combination of maintenance and upstream stabilization.

Floodwater and Sediment Damages.--Flood damage in the San Gabriel basin by violent and widespread flows of water and flood-borne sediment and debris occurs as destruction of land and buildings, highways, railroads, reservoirs, crops, pipelines, and other types of property. Flood damages are greater when extensive areas of bare soil in both mountain and agricultural areas are exposed to prolonged and intensive storms.

In the canyon bottoms floods cause damage by washing out roads, bridges, recreational areas, cabins, resorts, and buildings. Water diversions, intake structures, and pipelines are subject to damage or destruction. Water supplies are interrupted and water losses are sustained when the pipelines are broken or the water is too muddy to use and must be bypassed.

Flood-control reservoirs, debris basins, and improved channels at the canyon mouths along the mountain front are filled with debris, impairing their usefulness and effectiveness as well as creating an added hazard should they fail.

Water-spreading systems at the canyon mouths and on adjacent slopes of the nearby alluvial cones are similarly damaged. Diversion works for spreading grounds are destroyed or filled with boulders. Silt-laden waters cannot be used because they seal the spreading grounds.

The March 1938 flood caused damages in the San Gabriel-Coyote Creek

flood plain totaling $5,665,800. During the same flood in the Santa Ana basin, 43 lives were lost and property damage amounted to $13,957,700.

Damage started high in the mountains. In San Antonio Canyon, as an example, about 300 summer homes were destroyed. As the debris-laden waters poured into the valleys they damaged improvements of all kinds--spreading works, buildings, telephone and power lines, highways, bridges, railroads, flood-control improvements, agricultural land, and crops. Table 1 illustrates the extent of damage to various types of properties from large floods.

In addition to the damage listed above, channels, small debris dams, and water reservoirs suffered capacity loss through sedimentation during the 1938 flood. Figures are not available for this damage. Debris barriers at the mouth of Cucamonga Canyon were completely filled with sediment which has partially been mechanically removed. Excavation of sediment in channels resulting from this flood has been carried on extensively in order to regain lost capacity. In the San Gabriel watershed where about 231 square miles of mountain terrain were controlled by seven reservoirs a capacity loss of about 11,500,000 cubic yards of space resulted from sedimentation during the 1938 flood. Since the 1938 flood about 3,600,000 cubic yards of sediment have been removed from San Gabriel Reservoirs 1 and 2, Big Dalton Reservoir, Puddingstone Diversion, and the lower San Gabriel channel. Although complete records are not available to determine the total cost of this removal, cleaning costs for a number of frontal canyon debris basins with nearby disposal sites ranged from 19 to 92 cents a cubic yard.

Damages would have been much greater without the protection of the dams on the main San Gabriel River and many of its tributaries originating

Table 1.--Flood damages: 1/ 1938 storm, San Gabriel-Santa Ana watersheds, California

Character of property	Damage		
	San Gabriel River basin	Coyote Creek basin 2/	Santa Ana River basin
	Dollars	Dollars	Dollars
Residential	183,200	898,600	1,158,100
Business and industrial	176,300	548,400	1,370,800
Agriculture	242,600	1,445,200	2,669,300
Transportation facilities	483,100	278,100	4,276,900
Utilities	238,300	125,300	1,829,700
Communication systems	5,900	--	151,200
Channel improvements	461,900	53,000	1,593,700
Miscellaneous	513,600	12,300	908,000
Total	2,304,900	3,360,900	13,957,700

1/ Direct damages only

2/ Damages are largely from Santa Ana River overflow.

in the frontal mountains. The exceedingly high damage in the Coyote Creek basin was caused largely by the Santa Ana River which overflowed northwest of Anaheim following an old course to converge with the floodwaters of Carbon, Fullerton, La Brea, and Coyote Creeks.

The damages listed in table 1 will be reduced to a large extent by the flood-control works now constructed or authorized for construction by the Corps of Engineers.

Congress has authorized the Corps of Engineers to construct dams and channels in the lower basin to reduce flood damages along the main streams, but damages will continue on the smaller tributaries and above the existing and authorized flood-control works. Flood-retarding basins and improved channels provide flood protection downstream from the basins and on the lands directly adjacent to the improved channels. Even in the

mountainous areas, where development is limited, damage occurs to recreation developments, communication, transportation facilities, and commercial establishments. On agricultural lands damage results from concentration of runoff prior to its discharge into improved or protected channels. The sedimentation problem is accentuated by the construction of downstream reservoirs, channels, and flood-retarding works. Flood flows from the mountains are confined by the downstream flood-protection works which also receive the concentrated sediment loads.

Future damages from local floods in tributaries and headwaters of the San Gabriel watershed, including damages to expected future development, are estimated to average $386,200 a year. In the Santa Ana watershed the average annual flood damages under present watershed conditions and expected future economic development for the areas which are now either unprotected or only partially protected is $591,000.

ACTIVITIES RELATED TO FLOOD CONTROL

About fourteen authorized agencies--Federal, State, and County--have been engaged in the planning and installation of works related to flood control in this basin. Approximately $165,000,000 has been expended by Federal and local interests for flood-control structures and works of improvement.

The Department of the Army, Corps of Engineers, under existing authority of the Flood Control Acts, has constructed the following works of improvement on the Santa Ana River: (1) Prado Dam, located on the main Santa Ana River at a cost of about $9,450,000 in 1941. This structure is expected to reduce the flow of the design flood from 193,000 cubic feet per second to 9,200 cubic feet per second. (2) Lytle and Cajon Creeks channel improvements and bypass were completed in 1947 at an approximate

cost of $8,055,000. This system is expected to provide almost complete protection from a flood of 60,000 cubic feet per second in the overflow area between the mountains and Foothill Boulevard.

In addition, the Corps of Engineers has been authorized to construct: (1) San Antonio Dam and San Antonio and Chino Creeks channel improvements at an estimated cost of $13,543,000; (2) Villa Park Dam on Santiago Creek at an estimated cost of $2,100,000. House Document 135, 81st Congress, recommends the following additional projects: (1) concrete diversion channel and levee on Devil Creek, revetment of levees on Upper East Twin Creek, and a concrete channel on East Twin and Warm Creeks at an estimated cost of $10,163,000; (2) levee sections on Mill Creek near Mentone at an estimated cost of $975,000; (3) levees on the Santa Ana River near Riverside, estimated to cost $3,160,000; (4) levees on the San Jacinto River and Bautiste Creek near San Jacinto at an estimated cost of $3,279,000.

The Corps of Engineers has prepared a general plan of improvement for the San Gabriel River which was authorized for construction by the 76th Congress and published in 1938 as House Document No. 838. This plan proposed the construction of the Santa Fe and Whittier Narrows flood-control basins, seven debris basins at the mouths of tributary canyons, about 36 miles of main channel improvement, about 70 miles of tributary channel improvement, and 142 bridges over the main and tributary channels. Smaller flood-control basins have been authorized or constructed on Fullerton, La Brea, and Carbon Creeks. The total estimated cost (in 1940) of this program was $89,530,000.

Up to and including fiscal year 1948 a total of $107,035,000 had been expended in the construction of flood-control improvements in both watersheds. The Corps is currently authorized to construct additional

improvements estimated to cost about $33,220,000.

The Department of Agriculture through its several agencies has been active in land-management programs within the two basins. The Department is currently spending about $500,000 annually on certain measures and programs which directly contribute to waterflow retardation and erosion control. The Forest Service is responsible for the management of the 695,005 acres of national forest in these watersheds. Forest fire control, the principal activity with flood-control and associated water-conservation benefitis, has been a major function of this agency since the establishment of the Angeles National Forest in 1892. Some land has also been acquired for watershed protection purposes by the Forest Service. Under provisions of the Clarke-McNary Act of 1924 the Forest Service aids in protecting the cover against destruction by fire on 335,400 acres of watershed lands outside the National Forests.

Other activities of the Forest Service which have contributed materially to the reduction of runoff and erosion include the treatment of many miles of fire-control roads to reduce road-slope erosion and the emergency treatment of about 51,000 acres of new burned area. In addition, the research branch of this agency is conducting investigations in the watersheds to determine quantitatively the relation of the natural vegetation of the mountains to the water and sedimentation problems and to develop methods of watershed management.

The Soil Conservation Service, cooperating with Soil Conservation Districts, provides technical services for application of conservation practices and measures planned in cooperation with farmers.

The Production and Marketing Administration offers assistance to farmers in the form of a payment for part of the cost of carrying out

approved soil and water-conservation practices.

The Department of Agriculture cooperates with the State of California through its Land-Grant Colleges in an educational program to assist the farmers in developing more efficient farms.

The State of California cooperates with the Department of Agriculture under the provisions of the Clarke-McNary Act of 1924. Federal assistance is provided for the protection against fire of the cover on privately owned lands having a primary timber or watershed value. Under this Act, the California Division of Forestry protects about 316,700 acres in the Orange, Riverside, and San Bernardino Counties portion of the watershed, and the Los Angeles County Department of Forester and Fire Warden protects about 18,700 acres in the Los Angeles County portion of the watershed for the State.

The State Division of Highways also deals with local flood and erosion-control problems in its highway construction and maintenance work.

The State of California Department of Public Works, Division of Water Resources, has investigated the flood-control and water-conservation problems in both basins.

Currently, the Division is restudying the Santa Ana basin to determine the present status of water supplies, present overdraft for each sub-basin and the ultimate water requirements for the basin as a whole. The Department of Public Works also has assisted local interests in works of improvement for flood control and water conservation.

The Los Angeles County Flood Control District has constructed eight flood-control and water-conservation dams, many miles of improved channels, and numerous temporary check dams. Major works include San Gabriel dams

No. 1 and No. 2; Big Dalton, San Dimas, Puddingstone, Live Oak, and Thompson Creek dams; and Puddingstone Diversion. The total expenditure by the county up to 1940 was about $35,000,000. In addition, the Los Angeles County Engineer's Office has constructed many storm drains and appurtenant works for the disposition of flood flows.

The County of San Bernardino has constructed debris basins and about 37 miles of channel improvements including revetments, levees, bank protection and excavation at an estimated cost of $1,343,000.

The County of Riverside has improved about 73 miles of channel at a cost of about $1,598,000, in addition to the construction of 7,000 feet of storm drain and a series of small check dams at a cost of $254,000.

The County of Orange has constructed 20 miles of levee and improved 17 miles of channel at a cost of $2,310,000.

Cities and private concerns have constructed several dams, primarily for irrigation and domestic water storage. One of the largest--Morris Dam--built by the city of Pasadena, was acquired by the Metropolitan Water District of Southern California and incorporated into the District's distribution system as an emergency water supply reservoir.

In summary, the total past and current proposed flood control works and measures for the San Gabriel and Santa Ana Rivers will provide many of the necessary downstream controls, but will not provide adequate treatment of the watersheds to reduce runoff or silt and debris movement into the drainage system.

PLAN OF IMPROVEMENT

In the watersheds such as the San Gabriel and Santa Ana with their two distinct problem areas, one the mountains or wildlands, the other the valley agricultural lands, remedial measures logically fall into these

two broad groups. This grouping is further emphasized by the fact that major flood-control works either built or authorized to be built by the Department of the Army and/or County Flood Control Districts are primarily for control of floodwater and sediment from the mountain source area.

The recommended program to aid in the control of floods and sedimentation is designed to reduce flood damages and to protect and maintain the efficiency of the downstream flood-control and water-conservation works. It has been integrated with all existing and currently proposed works to meet the needs of a comprehensive program in aid of flood control. Substantial reductions in flood and sediment damages will be attained as well as many conservation benefits. The cost of the remedial measures is over and above all presently expended costs for administration and management by Federal and local agencies. Costs are based on 1946 prices.

An integrated program of cover maintenance, control of active sediment source areas, stream channel improvement and correction, and cropland treatment measures is recommended in this basin.

Proper management and treatment of floodwater and sediment source areas in the mountains or wild lands includes intensified fire protection, road slope stabilization, and land acquisition. Installation and operation, maintenance, and replacement costs are listed by individual measures in table 2.

Intensified Fire Protection.--An essential element toward accomplishment of the flood-control objective is adequate protection against wildfire. This can be obtained by improving fire prevention and control facilities over and above current fire prevention and control measures available to the existing protection organizations. Of the 1,025,300 acres

of wild land protected from fire, 60 percent is within the National Forests under protection of the U. S. Forest Service. About 30 percent is State or privately owned land for which protection is provided by the California Division of Forestry. The remaining 10 percent is protected by Los Angeles County.

To accomplish intensified fire protection, the following measures are recommended: Additional access and transportation facilities to permit speedier attack on all fires; improved detection and communication in reporting fire occurrences; additional water developments for fire suppression; buildings for equipment and fire-control personnel. The estimated cost is about $2,561,400 with annual maintenance, operation, and replacement costs of about $385,600. Of the total installation cost, $2,186,100 is for improvements on National Forest land and $375,300 for similar installations on State or private lands for which maintenance and operation are estimated to be about $131,700.

Total exclusion of fire cannot be expected within the limits of present knowledge or techniques. In spite of the intensity of protection, some fires will inevitably occur. To guard against excessive flood runoff and erosion damages following these fires, it is essential that the present Congressional authorization for emergency treatment of burned areas be implemented by adequate funds to accomplish the emergency measures.

Land Acquisition.--An essential aid to accomplishing maximum fire control effectiveness is the assurance that certain tracts of land located in the extremely high fire-hazard zone receive fire prevention effort commensurate with the protection afforded adjoining lands. Some 63 such tracts, totaling about 15,000 acres, are privately owned within or adjacent to the publicly owned National Forests. Public acquisition of

these scattered tracts will be a direct method of reducing fire occurrence by limiting the present unrestricted use where threat of fire is extremely high and local cooperation limited. Certain of these tracts are significant sediment source areas which cannot be remedied under present ownership. A number of them are essential for the location of facilitating improvements and sediment-control structures dependent upon adequate fire protection of the adjoining watershed lands.

Road Slope Stabilization.--Vegetative and structural treatment is recommended on about 135 acres of road slopes in conjunction with the improvement of road drainage facilities on about 200 miles of roads in this watershed. Slope fixation of actively eroding fill slopes will be accomplished by vegetative and mechanical methods to reduce the erosion contribution from this source. Additional adequate drainage facilities for the safe disposal of water collecting on and crossing the road will aid materially in reducing the erosion from and adjacent to the road.

The agricultural problem areas requiring treatment to reduce and control flood runoff and erosion are located on the sloping cultivated lands and the range and pasture hills in the lower half of the basin not now protected by existing or authorized flood-control works. Measures required to accomplish reduction of flood runoff and erosion on these lands and for reduction of local flood damages along minor streams include (1) the improvement of small community channels needed to carry floodwaters from small watersheds and farm runoff disposal systems into the larger channels; (2) the improvement of crop and range lands by land management practices.

Community Channel Improvements.-- The improvement of community channels in the lower basin consists of approximately 520 miles of waterways

to provide adequate, stable floodwater disposal systems. This includes stabilization of existing gullies, enlargement of inadequate channels, and channelization of flow on debris fans where agricultural development has encroached to almost eliminate natural stream courses. These improvements are in the nature of lined channels or conduits, debris basins, earth channels with vegetative or structural stabilization dependent upon specific site conditions.

Crop and Range Land Improvements.--All of the land adjacent to the many inadequate and small channels in the valley agricultural area is subject to varying types and degrees of flood damage. Furthermore, the crop and range lands present a variety of sediment-source conditions dependent upon site conditions, land use, and management. Where these agricultural lands are above existing or authorized flood-control reservoirs they contribute to the debris problem in these reservoirs. At the present time these lands are deteriorating by loss of soil resources. Their stabilization with continued intensive use requires improved land-use practices and waterway stabilization. The steeper portions of the agricultural land normally devoted to hay and grain production in dry-farmed areas have the highest rate of sediment production. This loss of soil has resulted in a marked decline in production and some severely eroded hills have been abandoned.

The recommended cropland measures include the following: (1) Terracing some 40,600 acres to reduce soil erosion; (2) improving farm runoff disposal systems on approximately 97,000 acres by vegetated waterways, small outlets and channel stabilization structures, and lined channels.

Range and pasture improvements on approximately 235,900 acres will

be accomplished by better land management involving controlled grazing and proper stocking of depleted lands. Approximately 14,800 acres of steep eroding lands now used for hay and grain will be seeded to range or pasture for erosion control. Other essential measures include fencing, water developments, and reseeding.

Technical services and direct aid will be provided for planning and applying land-use adjustments, conservation measures, and integrating the installation of individual measures into a proper combination to achieve the most effective program of runoff and waterflow retardation and soil erosion prevention.

Landowners and operators and others will be furnished educational assistance relative to the need for the recommended program and its purposes and objectives, and how to install and maintain measures not requiring detailed technical service.

Cost of the Program.--The estimated installation cost of the program recommended for adoption is approximately $32,556,500. Annual maintenance and operation costs will increase until they reach $927,500 after all measures are installed. Of the installation cost, it is recommended that the Federal Government expend about $24,890,100, non-Federal public agencies about $6,390,500, and private interests $1,275,900. The estimated cost of installing the program is shown in table 2.

Of the estimated average annual cost of maintaining and operating the program, the Federal Government will expend $332,800; non-Federal public agencies will expend $474,700; and private interests $120,000.

Distribution of Costs.--Installation of various features of the recommended program will be undertaken in cooperation with concerned State

Table 2.--Estimated costs for installation: San Gabriel and Santa Ana River watersheds

Measure	Total costs (1946-47 prices)	Annual operation, maintenance, and replacement costs (1946-47 prices)
	Dollars	Dollars
Intensified fire protection	2,561,000	385,600
Road slope stabilization	2,683,000	27,400
Community channel improvements	23,792,000	394,700
Farm runoff disposal	1,462,000	57,500
Terraces	776,000	33,300
Grass seeding	310,000	0
Range improvements	473,000	29,000
Land acquisition	500,000	0
Total	1/32,557,000	927,500

1/ Technical services, educational assistance, and administration of direct aids for crop- and range-land treatment amounting to about 2 percent are included as part of the costs of the measures in the agricultural areas.

and county governments, local communities, State Soil Conservation Districts, and private owners.

The Federal Government will bear the cost of the following measures regardless of ownership of lands on which installed: (a) All fire-protection measures on Federal lands and 50 percent of the cost on State and private lands, (b) all road slope stabilization costs on Federal roads and highways and part of the cost on all other roads and highways.

The Federal Government will bear the major cost of seed for improvement of range and pasture of certain high sediment producing non-Federal areas and will bear the cost of the necessary work for the stabilization of areas to be excluded from use.

The Federal Government will participate with other public agencies in the cost of installing community channel improvements and will contribute to the cost of installing farm runoff disposal systems, terracing and range improvement on private lands.

Local interests will contribute the balance of the installation cost. Unless otherwise determined by the Secretary of Agriculture, local interests will furnish without cost to the United States all necessary rights-of-way and easements on non-Federal lands.

Annual maintenance costs of fire control and road slope stabilization measures on Federal lands will be borne by the Federal Government. In addition, the Federal Government will bear half the maintenance cost of fire-control measures on State and private lands.

All other maintenance costs will be borne by local interests.

BENEFITS

Physical Effect.--Combined effects of all measures recommended will, in most instances, reduce excessive surface runoff and promote increased infiltration of rainfall into the soil and rock strata. Average reduction in flood damages will be about 50 percent. Sedimentation is estimated to be reduced about 20 percent which will reduce the costly maintenance of existing and authorized flood-control structures as well as maintain the design capacity of channels. Other benefits accruing from reduced sedimentation will be lessened flood peaks, conservation of valuable cropland, and maintenance of agricultural yields. Additional benefits from the recommended program will be reduced property loss by fire, enhanced recreational and wildlife values, reduced fire suppression costs, increased rental return on cropland, and increased water conservation. Realization of these effects will depend on the complete installation, maintenance, and operation of the recommended program.

Nonevaluated Benefits.--The program recommended for waterflow retardation and soil-erosion control consists of a combination of closely interrelated measures which produce benefits of a substantial and lasting nature. Certain of these benefits are readily evaluated in monetary terms, others are less susceptible to such analysis. However, many of the benefits which cannot be evaluated monetarily are so highly important in relation to the social and economic welfare of the watershed and the region of which it is a part that they also contribute to the justification for the program.

The program will result in an increase in the sustained annual production of agricultural produce and livestock. This increase will not only help stabilize and improve the economic condition of the owners and operators of the land but also that of local labor and the business dependent upon a steady community income.

Continued removal of topsoil by accelerated erosion will further reduce the productivity of the agricultural land. If this process is allowed to continue ultimate correction of these adverse conditions will become even more difficult and costly than today. Installation of the recommended program will reduce these excessive costs of the future in addition to maintaining the soil resource.

Reduction in the rate of soil removal from crop, range, and wild lands will be reflected in corresponding reductions in downstream sedimentation. Reduced sedimentation of water spreading ground, urban, and rural improvements, streets, irrigation facilities, and other improvements will extend the life of the agricultural enterprise and have a marked influence on the entire economy dependent upon it.

Other beneficial results will accrue from the program. The hazard of loss of life will be reduced. Minimizing existing uncertainties of flood and sediment flow will permit more stable planning by individuals and communities and encourage the highest use of watershed lands.

Monetary Benefits.--Future flood damages are expected to increase unless a remedial program is installed. Benefits 2/ are based on the difference between expected future damages with and without a program over an infinite period. Annual flood and sediment damage reductions will amount to about $490,800 and $156,700 respectively. Conservation benefits are estimated to amount to $1,366,400 annually. These benefits will accrue to landowners, operators, and local interests through maintaining crop yields at their present levels or, in some cases, increasing them above present yields. Through reduction in road maintenance, property loss by fire, and fire suppression costs annual benefits from the recommended plan will total about $415,600. Water conservation benefits due to reduced sedimentation in San Gabriel Reservoir No. 1 are estimated to be $7,700 annually. Attainment of the estimated benefits is dependent on the installation and proper maintenance of the recommended program. A summary of all average annual benefits is shown in table 3.

2/ For discounting purposes a 2-1/2 percent interest rate was used for Federal and other public costs, and a 4 percent rate for private costs.

Table 3.--Estimated annual value of future benefits

Item	Value
	Dollars
Flood damage reduction	490,800
Sediment damage reduction	156,700
Water conservation	7,700
Reduced fire suppression costs	77,200
Reduced road maintenance costs	187,600
Reduced property loss by fire	150,800
Crop and range conservation benefits	1,366,400
Total	2,437,200

COMPARISON OF BENEFITS AND COSTS

Benefits and costs in this report are based on prices existing in 1946 and 1947. In order to adjust costs and benefits to a price level expected to prevail in the future under a full employment level, cost and price indices were applied to the 1946-47 values in tables 2 and 3 which reduced benefits to $2,361,900 and increased costs to $1,916,900. The ratio of adjusted evaluated benefits to adjusted costs is 1.23 to 1.0.

UNITED STATES DEPARTMENT OF AGRICULTURE

APPENDIX 1

THE WATERSHED AND ITS FLOOD PROBLEMS

San Gabriel and Santa Ana River Watersheds, California

To accompany report on survey, flood control,
San Gabriel and Santa Ana River Watersheds, California

APPENDIX 1

THE WATERSHED AND ITS FLOOD PROBLEMS

San Gabriel and Santa Ana River Watersheds, California

The San Gabriel and Santa Ana River watersheds, lying east and adjacent to the Los Angeles River drainage embrace an area of about 3,183 square miles (2,037,000 acres) lying in Los Angeles, San Bernardino, Riverside, and Orange Counties in southwestern California. The rivers of the three watersheds enter the Pacific Ocean at points less than 15 miles apart, and the Los Angeles and San Gabriel flow into San Pedro Bay at points less than 5 miles apart. The drainage area of the San Gabriel is elongated and irregular, its northern third comprising a portion of the great mass of the San Gabriel Mountains and its southern two-thirds a gently sloping, densely populated valley floor interrupted midway to the ocean by low folded formations of the South, San Jose, Puente, and Coyote Hills.

The Santa Ana watershed is bounded on the north by the San Gabriel and San Bernardino Mountains which rise to an elevation of 11,500 feet at San Gorgonio Peak in the extreme northeastern corner of the basin. The eastern edge of the watershed is flanked by the San Jacinto Mountains while the north slopes of the Santa Ana Mountains delineate the southwestern corner of the basin. The northerly extension of the Santa Ana Mountains forms the Puente and Chino Hills. The valley portion of the basin is separated into two parts, the San Jacinto Valley to the east and the Cucamonga Valley to the north, by a low triangular-shaped block known as the Perris Block, somewhat elevated above the valley floor and containing several low mountains.

Having established the geographic location of the general problem area, the economic and physical elements of the problem need to be inspected. A flood must affect adversely the economy of an area before remedial action is warranted. The economic elements establish the need and to a large degree the justification for any control action. On the other hand, the physical components such as drainage pattern, geology, soils, cover, and climate influence not only the economy but also the physical magnitude of the flood and the degree to which flood damage may be reduced.

Economy.--Flood and debris flows affect the lives and welfare of about 900,000 people in the San Gabriel and Santa Ana watersheds. These people annually produce goods and services valued at 1947 prices at about $1,000,000,000. This production is continuing to increase with the rapid increase in population and industry. The urban part of the population lives in 43 towns. About one-fifth of the population finds its livelihood in the adjoining industrial areas of Los Angeles and Long Beach. The rest are occupied within the watersheds in the oil industry, small manufacturing trades, services, and agriculture.

The rural people draw their living from about 25,000 farms covering about 892,000 acres, of which 450,000 are irrigated. Citrus and avocado groves rank highest in area among the crops, the remainder are diversified

Table 1.--Land use, San Gabriel and Santa Ana River watersheds

Land use	Acres	Percent
Agriculture		
Citrus and avocados	235,000	11.5
Deciduous orchards and vineyards	83,000	4.1
Cereal hay and grain	170,000	8.3
Row, intertilled, and diversified crops	168,000	8.2
Range	236,000	11.6
Total agriculture	892,000	43.7
Other		
Watershed, urban, and vacant	1,144,500	56.3
Total other	1,144,500	56.3
Grand total	2,036,500	100.0

crops and pasture (table 1). Farms are generally small. Over 80 percent occupy less than 30 acres. The value of the land is high. Citrus groves sold for as much as $4,000 per acre during the war.

The San Gabriel and Santa Ana basins are important for their rail lines and highways which connect Los Angeles locally with Riverside and San Bernardino and nationally with southern and eastern United States.

In the San Gabriel watershed about 280,000 acre-feet of water are used annually within the watershed. Farmers use 240,000 acre-feet for irrigation and livestock. The underground basins supply about 90 percent of the farmers' need through pumping, the rest comes from direct diversion from San Gabriel River and its tributaries. The urban centers rely for their water supply largely upon Colorado River water which is furnished by the Metropolitan Water District. The people have preserved much of the mountain water by construction of storage reservoirs on almost every stream. Water-spreading facilities have been built in many parts of the watershed for recharging the receding underground basins.

Water is particularly important in the economy of the Santa Ana basin. The demand for it in neighboring basins has necessitated local requirements to be met almost entirely from sources within the watershed. Diversions from the Santa Ana River and its tributaries are estimated to supply about 16 percent of the water used. The remainder is pumped from natural underground storage basins and a small amount is imported from the Colorado River for domestic use. The underground basins are replenished by natural seepage. Only during large floods is water lost to the ocean.

The local water supply is apportioned under water rights established by long usage, court decrees, or compromise agreements. Water is supplied by public utilities, municipally owned plants, irrigation districts, mutual water companies, and privately owned pumping plants. The average annual use amounts to 683,000 acre-feet. As near as can be determined the demand exceeds the supply by 13,000 acre-feet annually. As a result the water table is slowly receding in the coastal plain and in the lower part of the interior valley. Recently a program was launched in Orange County which promises to relieve the present heavy draft on the lower underground basins. About 13,000 acre-feet of Colorado River water was released in the Santa Ana River channel for direct diversion to two irrigation and water companies to eliminate their pumping of ground water. Some of this released water has percolated underground. Nevertheless, continued agricultural and industrial development will necessitate an increased supply of water. Average costs of all water used have been estimated by the Corps of Engineers at $9 per acre-foot for irrigation water and $35 for domestic use.'

The mountain land is mostly owned by the Federal Government and the valley land is almost completely in private ownership (table 2).

Table 2.--Land ownership, San Gabriel watershed

Status of ownership	Acres	Percent
Private	1,408,700	69.2
Federal (national forest)	566,800	27.8
Municipal, county, and State	61,000	3.0
Total	2,036,500	100.0

Climate.--The San Gabriel and Santa Ana watersheds have a Mediterranean climate. The seasons are characterized by long, dry summers and relatively short, mild winters.

The major portion of the precipitation occurs during the four months, December through March, Normally, no rain falls from May to September. Mean seasonal precipitation varies from 12 inches at the coast to 22 inches at the base of the mountains (1,000 feet elevation), to over 44 inches on Mount Baldy (elevation, 10,080 feet). Precipitation for individual years has varied from one-half to two times the mean. Storms are generally characterized by high-intensity rains causing floods when falling on saturated watersheds.

The average daily temperature at Los Angeles for the summer months is 66.6 degrees F. while the winter period--November through March--averages 57.6 degrees F. Freezing temperatures occur occasionally in the valley areas during the winter, requiring smudging of the citrus crops. Maximum and minimum temperatures of record at Santa Ana are 112 degrees F.

and 22 degrees F., respectively, with an average annual temperature of 62 degrees. The temperatures recorded at San Bernardino are more extreme--maximum of 116 degrees F. and minimum of 17 degrees F. with an average annual temperature of 63 degrees. The average frost-free period at Santa Ana is 300 days and at San Bernardino 260 days. The mountain areas above 5,000 feet experience frequent freezing winter weather with snow packs occasionally remaining into April.

The prevailing westerly winds are of light to moderate velocities. Occasional high velocity northeasterly winds sweep into the watershed from the Mojave Desert plateaus. These winds, known locally as "Santa Anas," frequently exceed 50 miles an hour and occur most commonly during fall, winter, and spring months.

The average annual sunshine is 72 percent of the maximum possible.

Drainage Pattern.--The San Gabriel River rises at the northern end of the watershed and flows in a southwesterly direction about 60 miles. It enters the ocean 5 miles east of Long Beach. The main river and its tributaries drain an area of 703 square miles.

From the river's source to its emergency on the alluvial plain the main stream and its tributaries flow through an intricate system of deep and steep canyons carved in the shattered unstable mountain mass. High stream velocities and torrential flows characterize these streams during flood periods. The gradient of major tributaries such as the West Fork of the San Gabriel averages about 8 percent. Smaller tributaries frequently exceed 40 percent and channel side slopes often are in excess of 100 percent. Many tributaries of the San Gabriel Mountain front such as Fish Canyon have gradients in excess of 15 percent.

Many of these mountain channels have accumulated deep and extensive deposits of debris between major storms which transport the material downstream.

Where the river and its tributaries pass from the mountains to the upper valley plain gradients change from about 5 percent to 1 percent. Here, during the flood stage, streams drop the heavier particles of their debris loads to form the huge alluvial cones characteristic of this area. The poorly defined and indefinite water courses in the alluvial fan and valley areas are readily blocked so that streams overflow, spreading their water and debris over groves, residential developments, roads, and rails. The whole upper alluvial plain, covering about 145 square miles, extends from the foot of the mountains to the chain of valley hills, a distance of only 5 miles. The land is gently sloping and the streams continue to drop their load of finer materials throughout this course. Stable channels cannot become established and floodwaters meander over fairly wide areas although the land adjacent to the channels may build up.

Debris is dropped continuously en route and new sediment is fed the streams by water collecting and running off the agricultural land. As stream water is lost through seepage into the porous valley fill it is augmented

by the many tributary streams of the rugged brush and grass-covered low hills that cross the central part of the watershed from east to west. These hills cover about 105 square miles.

When the river finally enters the coastal plain, an area of about 173 square miles, the slope of the land becomes still less and the channel gradients continue to decrease as they near the ocean. The bottoms of many channels that join the river near the ocean have been built up by sediment transported from the hills and from the agricultural land until they are level with the surrounding fields. The winter flows tend to break out, flood the country, and do not drain off until the creeks have run dry.

The major tributary streams of mountain and valley hills and their drainage areas are given in table 3. Areal extent of topographic units and range in elevations are shown in table 4.

Table 3.--Main tributary areas, San Gabriel River watershed

Names of principal tributaries	Drainage area
	Square miles
Mountain	
North, East, and West Forks of San Gabriel River	202
Fish, Roberts, and Van Tassel	25
Little Dalton	11
Big Dalton	17
San Dimas	26
Valley hills	
Walnut Creek	41
San Jose	84
Coyote	182
Small miscellaneous drainages	115
Total	703

Table 4.--Areal extent and range in elevations, San Gabriel River watershed

Topographic units	Area	Percent of total	Range in elevation
	Sq. mi.	Pct.	Feet
Upper San Gabriel Mountains	280	40	750 - 10,000
Valley hills	105	15	150 - 1,700
Upper San Gabriel valley basin	145	20	700 - 1,200
Coastal plain	173	25	0 - 300
Total	703	100	0 - 10,000

From its source in the San Bernardino Mountains the Santa Ana River flows westward for about 25 miles. In the lower part of this reach, and after leaving the mountain area, the Santa Ana River is joined by its principal tributaries: Mill, San Timoteo, Cajon, and Lytle Creeks. It then flows southwestward along the southeast margin of the San Bernardino Valley to Prado where it flows through a twelve-mile gorge in the Santa Ana Mountains, then across the coastal plain past the city of Santa Ana to the Pacific Ocean. The total length of the Santa Ana River is only about 100 miles, but continuous flow throughout its length is evident only during winter flood periods.

The flow of tributary streams is also intermittent. The valley fill over which the streams flow absorbs much of the mountain discharge before it joins the main river. Channels likewise have a tendency to divide and disappear. During flood the mountain reaches of the streams are heavily laden with debris. On leaving the steep mountain canyons they lose their transporting power and the debris load is dropped, save for the fine material, which is moved farther downstream. Extensive spreading works have been installed to augment natural percolation in these channels.

Stream flow in the San Jacinto River drainage is continuous only during flood periods. Water from this drainage flows into Lake Elsinore, which overflows into Temescal Creek only during major floods.

All streams in the valley sections at present appear to be aggrading. The flow from large storms accomplishes considerable scour, but the great number of small storms more than compensate for this, and the net result is gradual aggradation.

Land Cover.--The natural plant cover is an important factor in the flood and sediment problems of the watersheds. Its ecological characteristics, its density, and its treatment all influence the normal runoff and erosion regime. As would be expected in a drainage basin having the topographic characteristics previously described, the cover on the land is quite variable. The mountain mass is covered largely with brush or chaparral and trees. The plant cover on the valley hills is principally grass and mixed brush. The upper valley basins and coastal plains are now almost completely developed and where agriculture is practiced citrus production, diversified crops, and livestock growing are the leading uses. (See table 5.)

The plant cover of the mountains, predominantly chaparral species and chamise, is highly drought-resistant and can withstand considerable misuse. Many of the species sprout from the roots after destruction by fire and as a result other species incapable of withstanding repeated burning have been restricted. Chamise and chaparral form a good cover to break the force of high-intensity rains and thus protect the soil from excessive erosion.

The following broad plant types cover the wild-land areas in the watershed:

Chamise type is a low, sparsely-covered brush type. The predominant

species is chamise (Adenostema fasciculatum) intermixed with such other brushy plants as mountain lilac, manzanita, and sage. This type is found on lower elevation, south-exposed, poor sites and is a poor litter producer.

Chaparral type is predominantly scrub oak (Quercus dumosa) intermixed with mountain mahogany, mountain lilac, and toyon. It is a middle-elevation type favoring better sites, recovering rapidly from fire, and producing a good litter cover.

Coniferous type is a high-elevation, good-site type made up of various mixtures of pines, fir, and big cone spruce.

Grasslands are found in the South, Puente, and San Jose Hills areas. Heavy grazing and burning have reduced the cover to annual grasses and heraceous plants of generally poor soil-protection characteristics.

Sage type is dominated by white sage (Salvia apiana) and black sage (Salvia molifera) with other sages, buckwheat, and chamise associated. This type exists on the poorest sites and produces a poor litter cover.

Oak woodland type is dominated by canyon live oak (Quercus chrysolipis) and is found in the middle elevations. This "high" or tree form occupies the best sites, principally north-exposed slopes, and develops an excellent litter cover.

Barren and semibarren areas include talus; sliding slopes; raw, eroding channel beds; and rock outcrops. Many of the talus and rock outcrops are at higher elevations in headwater sections. Sliding slopes and eroding channel beds extend throughout the watershed.

The precipitous slopes which characterize the mountain area have developed a soil mantle of such fine material that only vegetation could have prevented it from falling from the slopes by the force of gravity alone. The development of such soil-covered slopes has been possible largely because of the soil-binding effect and adequate infiltration rates afforded by the vegetation. All vegetated slopes, then are a manifestation of an adjustment between aggradational and degradational forces in which the plant cover is the key to stability. Without it the soil and rock-waste mantle will be released.

This rather delicate adjustment permits normal erosional processes of varying rapidity and consequence to continue to operate. However, the reduction of the plant cover below critical density for protection sets in action violent erosional processes. Surface runoff is increased. Erosion is accelerated and more sediments are added to the normal stream load.

Reduction of plant cover not only accelerates the erosion of soil from slopes, but the increased volume of runoff and debris cuts into the canyon and valley fill.

The interrelation of plant development and soil stability has had a marked influence on soil formation in this watershed.

Table 5.--Land cover, San Gabriel and Santa Ana watersheds

Cover	Area	Percent of watersheds
	Square miles	
Agricultural	1,025	32.2
Residential and miscellaneous	151	4.7
Chamise	646	20.3
Chaparral and woodland	366	11.5
Coniferous	241	7.6
Grass	179	5.6
Sage	457	14.4
Barren and semibarren	118	3.7
Total	3,183	100.0

Geology and Soils.--The San Gabriel and San Bernardino Mountains are made up of a large number of formations which, for convenience, have been grouped together and referred to as the Basement Complex. It includes the oldest rocks in the watershed and is composed of schists, gneisses, granites, diorites, quartzites, and limestone. The San Jacinto range and the mountain-like hills scattered throughout the southeastern part of the watershed are less complex and principally granitic in character.

The southern California area, during Cretaceous and Tertiary periods, was inundated by the sea at several different periods and for varying lengths of time. The sediments deposited during these periods vary greatly in thickness and lithological character. The last widespread inundation occurred in the Pliocene Epoch when over 6,000 feet of conglomerate sands and shale were deposited. The sand and clay beds of the San Timoteo, Bautiste, and Eden areas were formed by deposition of these materials in the shallow playa-like lakes which existed in the eastern part of the watershed at that time.

Late Tertiary or early Quaternary time was marked in southern California by extensive land deformation. The San Gabriel and San Bernardino Mountains were uplifted many thousands of feet. Uplift was not continuous and rejuvenated erosion followed each period of uplift. The steep rolling terrain of the Bear Lake-Arrowhead Lake Plateau, is typical of the surface which existed over the whole region. Accompanying the uplift was a process of depression of adjacent blocks. The rejuvenated streams brought down vast quantities of debris. The most conspicuous topographic development on the valley floor is the formation of extensive alluvial fans which have accumulated to a depth in excess of 2,000 feet along the Cucamonga front.

The eroded material forming these fans consists of a heterogeneous mixture ranging in size from very large boulders to sand and silt particles.

Boulders usually are found on the fan-heads, the size diminishing with distance from the canyon mouth. Table 6 indicates the range in size of fan material expressed as the median of the lengths of the ten largest fragments found in a distance of 50 yards along the wash. 1/

Table 6.--Size of fragments on fans

Fan	Size at fan apex	Fan slope	Size $2\frac{1}{2}$ miles from fan apex	Fan slope	Size 5 miles from fan apex	Fan slope
	Inches	Percent	Inches	Percent	Inches	Percent
Lytle Creek	87	3	54	2.5	30	1.7
San Antonio	69	5	54	3.5	26	2.6
Cucamonga	90	5	30	4	22	2.5
Day Creek	112	10	21	4	13	2
Dear Creek	157	16	19	4	8	1

Flood flows discharging from the mountain canyons cut their own channels, choking them with debris, and again cutting new paths. This process occurred repeatedly as the debris fans were built by these flows, swinging first to one side then to the other side of the fan. Since these fans sometimes are highly developed residential areas, flood damages are enormous when the unconfined discharges suddenly change direction as they flow over the fan.

Major fault lines cross the Santa Ana watershed in a northwest-southeast direction. The most important fault, the San Andreas, separates the San Bernardino Mountain block from the San Gabriel and the San Jacinto ranges. The San Jacinto fault extends diagonally into the southeast corner of the watershed. Other major faults include the Cucamonga at the base of the San Gabriel Mountains, the Mission faults, which cut through the San Bernardino block, and the Chino and Whittier faults, which comprise the Elsinore fault zone. Innumerable smaller faults are of widespread occurrence throughout the watershed, but they are particularly noticeable in the San Gabriel and San Bernardino Mountain blocks.

Uplift and multiple faulting have resulted in a badly fractured rock mass, especially in the headwaters of the San Gabriel Mountains and in Mill Creek in the San Bernardino Mountains. In these areas ancient landslides have determined to a great extent the present topography. The

1/ Rollin Eckis, "Alluvial Fans of the Cucamonga District, Southern California," Jour. Geol., Vol. XXXVI, No. 3, April-May 1928, pp. 224-247.

existing topographic features exhibit evidence of landslide activity, such as extremely steep slopes where slides have broken away from the ridges; canyons dammed with accumulated slide material which streams are gradually cutting away; and an over-all mantle of loose angular rock fragments subject to downward creep.

Most of the soils on the mountain slopes are a residual product of rock weathering and plant development. They are relatively immature and reflect directly the type of rock from which they were formed.

About 33 percent of the mountain area is made up of the Basement Complex which forms soils ranging in depth from a few inches to three feet, relatively high in permeability and erodibility. The granodiorites, occupying about 29 percent of the mountain area, form a very shallow soil averaging about 6 inches in depth. It, too, is relatively high in permeability and erodibility. Characteristics of the other mountain soil groups are shown in tables 7 and 8.

As a result of the tremendous amount of fracturing found throughout the rock mass of the San Gabriel and San Bernardino Mountains considerable capacity exists for the reception and temporary storage of water. Rainwater percolating through the soil and entering the numerous cracks and crevices of the shattered rock gradually works down to a point of release which may be a spring in a canyon or some subterranean point along the mountain front deep under the valley fill.

This capacity to receive and store water is very important in any consideration of water relations because the relatively shallow depth of the mountain soil alone has limited capacity for water storage. Nevertheless, the function of the soil as a temporary retarding basin for supplying water to the underlying rock crevice channels is important. The soil, with its covering of vegetation and litter, collects the falling rain and prevents its surface channelization as long as its infiltration capacity is not exceeded. Consequently, one of the greatest functions of the mountain mass is as a catchment and water storage reservoir. This function operates at a maximum only when vegetation is present to maintain high infiltration--the first step in the storage process.

The agricultural soils of the watershed have been described, mapped, and classified by the Bureau of Chemistry and Soils in published reports on the Riverside area (1917), Anaheim area (1919), and Pasadena area (1917), and in a Reconnaissance Soil Survey of Central Southern California Area (1921). The Division of Physical Surveys of the Soil Conservation Service has completed a more detailed study of most of the valley and foothill soils of the basin. The more important soils are grouped according to origin and degree of profile development.

Group 1.--Alluvial soils with uniformly permeable profile on recent alluvial fans or recent valley fill. Organic content and water-holding capacity is low and the infiltration rate is high. These soils, used principally for citrus, deciduous orchards, or vineyards, occur extensively in the agricultural areas north of Riverside.

Table 7.--Mountain Soil Characteristics, Santa Ana River Watershed 1/

Soil group	Geologic formation	Soil age	Percent of total mountain area	Soil depth		Water storage 4/			Permeability	Erodibility	Substratum	
				Average	Range	WP 2/	WP to FC	FC to sat. 3/			Permeability	Porosity
				Feet	Feet	Inches						
San Gabriel	San Gabriel formation, metamorphic complex	Recent	2.9	3	0-8	1.2	1.5	12.4	High	High when exposed	Moderate	Low to moderate
Bouquet	Pelona schist	Recent	6.2	2	1-3	1.2	1.2	3.2	High	Low	Low to moderate	Low to moderate
Wilson	Acidic intrusives, diorite, Lowe granodiorite, monzonite	Recent	28.5	½	0-2	.2	.2	2.0	High	High	Low	
Crystal	Landslides and fanglomerates--unconsolidated	Recent	0.3	½	0-1	.3	.6	1.6	High	High when exposed	Very high	Very high
River-wash	Riverbed, flood plain, recent alluvium	Recent	7.8	--	--	.4	.5	4.0	High (infiltration rate low if water table high)	Low	Very high	Very high
Terrace	Quaternary terraces(unconsolidated and gravelly)	Immature	8.2	4	3-6	7	7	6.5	Medium to low	High when exposed	Very high	Very high

continued

Table 7.--Mountain Soil Characteristics, Santa Ana River Watershed - contd.

Soil group	Geologic formation	Soil age	Percent of total mountain area	Soil depth: Average	Soil depth: Range	Water storage [4]: WP [2]	Water storage [4]: WP to FC	Water storage [4]: FC to sat. [3]	Permeability	Erodibility	Substratum: Permeability	Substratum: Porosity
				Feet	Feet	Inches	Inches	Inches				
Castaic	Poorly consolidated sediments, mostly sandstones	Recent	1.2	1	0-2	.6	1.2	3.2	High	Moderate	Very high	Very high
Violin	Consolidated conglomerates, sandstones, shales	Recent	1.3	2	1-3	3.4	3.4	1.6	Moderate	Moderate	Moderate to high	Moderate to high
Frigid	Cajon sediments (consolidated sandstone)	Immature	3.4	3	2-6	4.0	4.6	6.4	Medium (subsoil low)	High	Low	High
Compromise	Igneous and metamorphic basement complex, well-mixed	Recent	32.8	1	0-3	.6	1.2	3.2	High	High	Low	Low
Baldwin	Saragossa quartsite, Arrastre quartsite	Immature	4.5	3	2-5	4.0	4.6	6.4	High	High when exposed	Low to moderate	Low to moderate
Furnace	Furnace limestone	Young	2.9	2	0-5	1.2	2.4	6.4		Moderate	Moderate	Moderate

1/ E. A. Colman, California Forest and Range Experiment Station, 1945.
2/ Wilting point.
3/ Field capacity to pore space saturation.
4/ Water storage values are for the average soil depth, except for Riverwash which is in inches per foot of depth.

Table 8.--Mountain Soil Characteristics, San Gabriel Watershed 1/

Soil Group	Percent mountain area	Geologic formation	Soil age	Soil: Texture	Soil: Depth: Aver. (Feet)	Soil: Depth: Range (Feet)	Water storage 4/: WP 2/	Water storage 4/: WP-FC	Water storage 4/: FC to sat. 3/	Permeability	Erodibility	Substratum: Permeability	Substratum: Porosity
San Gabriel	56.0	San Gabriel formation (metamorphic complex)	Recent	Sand, sandy-loam (rocky)	3	0-8	1.2	1.5	12.4	High	High when exposed	Moderate	Low to moderate
Wilson (shallow)	34.8	Acidic intrusive (Wilson & Parker diorite, Lowe granodiorite, monzonite)	Recent	Gravelly-sand, sandy-loam	½	0-2	.2	.2	2.0	High	High	Low	Low
Bouquet	7.1	Pelona Schist	Recent	Sandy-loam (rocky)	2	1-3	1.2	1.2	3.2	High	Low	Low to moderate	Low to moderate
Crystal Lake	1.1	Landslides, fanglomerates (unconsolidated)	Recent	Bouldery, gravelly, sandy-loam	½	0-1	.3	.6	1.6	High	High when exposed	Very high	Very high
Terrace	0.6	Quaternary terraces (unconsolidated & gravelly)	Immature	Loam-clay loam	4	3-6	7	7	6.5	Medium low	High when exposed	Very high	Very high
River Wash	0.4	River ted, flood plain, recent alluvium	Recent	Gravelly, sandy-loam	Indet.	Indet.	.4	.5	4.0	High (infil. rate low if water table high)	Low	Very high	Very high
Johnstone	0.1	Tertiary volcanics (Andesite and basalt)	Young	Clay-loam	4	2-8	6.8	6.8	6.4	Low to moderate	Moderate	Low to moderate	Low to moderate

1/ California Forest and Range Experiment Station. Fire Damage Appraisal. E.A. Colman.
2/ Wilting point. 3/ Field capacity to pore space saturation.
4/ Water storage values are for the average soil depth, except for Riverwash which is in inches per foot of depth.

Group 2.--Alluvial soils with moderately reduced permeability through the profile on unconsolidated recent alluvial or valley fills. The most common occurrence of this group is south of Chino and in the Warm Springs area. The most extensive use is for truck, grain, or field crops.

Group 3.--Alluvial soils with well developed profile derived from unconsolidated material on terraces and old alluvial fans. When cultivated this soil is easily eroded; organic content and water-holding capacity is moderately low where the soil is shallow and the infiltration rate is considerably less than the soils in group 1. This group occurs frequently on old terraces and old valley fills and is most extensive in the Perris and Hemet Valleys.

Group 4.--Alluvial soils with strongly developed profile having distinct clay pan or hard pan--formed on old alluvial plains or other old alluvial surfaces. The surface soil varies from 10 to 16 inches in depth. Shallow soils are best suited to pasture although some are used for dry-farmed grain. Soils of this group are highly susceptible to erosion when sloping lands are cultivated. Yields are usually low. Extensive areas of this group are found near Redlands, in the Yucaipa area and in the vicinity of Riverside. South and southwest of Redlands and east and southeast of Riverside surface soils of this group, generally over 12 inches in depth, produce excellent citrus when irrigated. Sheet erosion is active where faulty cultural practices are used.

Group 5.--Residual soils derived from relatively unconsolidated sedimentary parent material. No important agricultural development occurs on this soil group. Although a small acreage is dry-farmed in the Chino hills area, most of this group is classed as "badlands" and occurs southwest of Beaumont and in smaller areas east of Hemet.

Group 6.--Residual soils derived from semiconsolidated sedimentary parent material. On moderate slopes surface soils, generally dry-farmed, are from 12 to 18 inches deep and subject to severe sheet erosion. The most extensive areas are in the Chino hills and in the foothills of the Santa Ana Mountains.

Group 7.--Residual soils of agricultural value derived from granite and metamorphic rocks. They usually occur along the steep margins of granite hills, are generally quite shallow and low in organic content. These soils are common along the margins of the Perris Valley and on hills to the west. Agricultural use is very limited; and when slopes of 5 percent or over are cultivated, erosion is heavy.

The physical characteristics of the watershed and the long and varied use both valley and mountains have experienced is reflected in the extremely high sediment hazard present throughout the basins. Repeated fires followed by extremely high precipitation have choked channels with debris and created a source of material incapable of stabilization by fire protection alone. Heavy and intense use of many of the valley areas has created similar debris and sediment sources which proper use alone cannot eliminate. The net effect has been a lessening of the watershed's capacity to resist floods.

Consequently, this extremely unstable mountain mass with its thin soil, the highly erodible valley soils, the relatively sparse yet highly inflammable watershed cover, the short winters characterized by high intensity rainfall--all combine to make flood control a complex and costly effort. In spite of these adverse conditions, accomplishments have been made toward protection of the valley economy from flood damage as indicated by the activities of Federal, State, and county agencies in this watershed.

Current Flood Control Activities.--Both structural and vegetative means have been used to provide flood protection in the San Gabriel and Santa Ana watersheds. Structures such as detention and retarding dams, levees, revetments, improved and lined channels, debris basins, and check dams have been used to retard and confine flood flows. Large detention dams have been constructed in the mountain canyons for flood control and water conservation.

1. San Gabriel Watershed

A large retarding dam has been constructed below the mouth of the main San Gabriel Canyon to control flood discharges through the valley area. Below this dam the channel has been improved to carry the regulated flow. Debris basins are proposed at the mouths of many smaller tributary frontal canyons to desilt the flood flows prior to their discharge into improved valley channels which will empty into the large retarding dam or main channels. These works have been or will be constructed by the Los Angeles County Flood Control District and the Department of the Army, Corps of Engineers.

The Department of the Army, Corps of Engineers has prepared a general plan of improvement which was authorized for construction by the 76th Congress and published in 1938 as House Document No. 838. This plan proposed the construction of the Santa Fe and Whittier Narrows flood-control basins, seven debris basins at the mouths of tributary canyons, about 36 miles of main channel improvement, about 70 miles of tributary channel improvement, and 142 bridges over the main and tributary channels. Smaller flood-control basins have been authorized or constructed on Fullerton, La Brea, and Carbon Creeks. The total estimated cost (in 1940) of this program was $89,530,000.

Up to and including fiscal year 1948 a total of $14,763,900 had been expended in the construction of Santa Fe flood-control basin and the main river channel improvement between the basin and the canyon mouth.

When the work of the Corps and the county is completed, protection will be provided for areas below the mountain front that are subject to damage by flood flows from the San Gabriel River, Walnut and Coyote Creeks. The authorized debris basins will desilt floodwater before it enters the improved channels. Periodic removal of debris from the basins will therefore be necessary. The retention and retarding reservoirs will also function as desilting works, consequently they too will require cleaning.

The current programs of the Department of Agriculture also have contributed to the flood-control efforts in the basin. Through the regular activities of the Soil Conservation Service, the Production and Marketing Administration, the Agricultural Extension Service, and the Forest Service many conservation and erosion control measures and practices have been instituted on the watershed lands.

The Soil Conservation Service, cooperating with Soil Conservation Districts, provides technical assistance for application of conservation practices and measures planned in cooperation with farmers. The Service provides technical assistance for work in the field of soil erosion and flood control in the watershed as part of its activities. It is estimated the Service spent $10,000 a year for technical assistance in the San Gabriel River watershed on work directly related to the objectives of the Flood Control Act. Major practices in 1949 were contour farming, cover crops, range and pasture improvements, and farm and ranch ponds. Technical cost to the Federal government includes necessary conservation and range condition surveys for planning and application of conservation programs. The surveys include an inventory of all land, soil, and cover types, land capability, and condition of land and cover under present use.

The Production and Marketing Administration offers assistance to farmers in the form of a payment for part of the cost of carrying out approved soil and water conservation practices. This assistance may be in the form of materials and services, or cash payments. These payments are, in general, intended to defray about half the cost of the practice. In 1949 the Production and Marketing Administration made Agricultural Conservation Program payments in the watershed totalling about $73,000. Major practices in 1949 which had value for waterflow retardation and soil erosion prevention included the following annual practices: 2,600 acres of crop residue management; 4,700 acres of subsoiling; 1,600 tons of mulching; grazing land management on 21,400 acres; 16,300 feet of fire guards (or breaks). Permanent installations since beginning the program included: planting 160 acres of orchard or vineyard on the contour; 11,000 square feet of riprap; permanent cover on 171,300 square feet of permanent cover; construction of 22 flumes or chutes; 1,000 cubic yards of brush or rock dams; improvement of irrigation systems involving 71,000 feet of pipe and 300 cubic yards of concrete; development of seeps or springs totalling 68,000 cubic feet; stock water dams, 82,000 cubic yards; 20,000 feet of stock trail; 1,600 acres of permanent pasture; 20,000 rods of fencing; and 70 acres of planted trees.

The Agricultural Extension Service cooperating with the Department of Agriculture has, among other activities, an education program aiding farmers and ranchers in improving farm and ranch conservation practices directly related to soil erosion control and flood-control work.

The Forest Service manages and protects 164,723 acres of Angeles National Forest within the watershed. This amounts to about 35 percent of the total watershed area, all located in the mountain headwaters. The Angeles National Forest was established by Presidential Proclamation in

1892 for watershed protection. A key function of this agency has been the protection of the Federally-owned watersheds from fire. Fire protection facilities installed since the establishment of the National Forest include about 460 miles of roads and trails, about 15 buildings to house equipment and fire control personnel, 3 lookout stations, about 480 water developments, some 170 miles of firebreak, and about 80 miles of telephone line. At present, the Forest Service expends about $63,750 of Federal money for fire prevention and control in this watershed.

Erosion control measures have been installed on many of the fire control roads to reduce road fill slope erosion. As an emergency protection measure the Forest Service has sown about 330 acres of new-burned area with seed of quick-growing annual plants to establish a protective cover. The research branch of the Forest Service has established a 17,000-acre experimental forest area within the drainage to conduct the following general types of investigations: (a) quantitative determination of the relation of chaparral vegetation to the yield of usable water from mountain watersheds and its function in reducing erosion; (b) develop methods of management or treatment of the vegetation in order to maintain a maximum yield of usable water with a minimum amount of erosion.

The State of California, Department of Natural Resources, Division of Forestry, cooperates with the U.S. Department of Agriculture under provisions of the Clarke-McNary Act to provide fire protection to privately owned lands having a primary timber or watershed value. The total area of State and private lands in this classification is about 10,700 acres in the San Gabriel watershed. Clarke-McNary money used in 1949 was estimated to be about $800 which is about 22 percent of the total amount spent by the State to protect these lands.

The State of California, Department of Public Works, Division of Highways, also has contributed to the reduction of sedimentation by road slope fixation works and surface drainage improvements.

Three county agencies have contributed materially in the field of flood control, the Los Angeles County Flood Control District, the Los Angeles County Engineer's Office, and the Los Angeles County Forester and Fire Warden.

The Los Angeles County Forester and Fire Warden's organization has provided fire protection to about 18,700 acres of watershed land which qualify under the Clarke-McNary Act for Federal assistance. The State of California contracts the County Forester and Fire Warden to protect this acreage for which about $1,900 of Federal money was expended in 1949. In addition, this agency has installed emergency measures on about 300 acres of watershed burned area to hasten the recovery of vegetation and reduce erosion. Erosion control measures also have been installed on road fill slopes to reduce the sediment contribution to downstream developments.

The Los Angeles County Flood Control District was organized under authority of a State law enacted in 1915. All major flood control and water conservation projects were constructed by the Flood Control District in accordance with a comprehensive plan formulated prior to 1935. Since 1935 permanent improvements have been constructed in cooperation with Federal and other agencies. Flood control improvements constructed include eight flood control and water conservation dams, many miles of improved channels, and several hundred check dams. The major works include San Gabriel dams No. 1 and No. 2, Big Dalton, San Dimas, Puddingstone, Live Oak, and Thompson Creek dams, and Puddingstone diversion. The total expenditure by the county up to 1940 was about $35,000,000.

The Los Angeles County Engineer's Office has constructed many storm drains and appurtenant works for the disposition of flood flows.

Cities and private concerns have constructed several dams, primarily for irrigation and domestic water storage. One of the largest, Morris Dam, built by the City of Pasadena, was acquired by the Metropolitan Water District of Southern California and incorporated into the District's distribution system as an emergency water supply reservoir.

The total existing and current authorized flood-control works for the San Gabriel River will provide many of the necessary downstream controls, but will not provide the essential watershed treatments necessary to reduce runoff or silt and debris movement into the drainage system.

2. Santa Ana Watershed

Large-scale efforts toward the reduction of flood damages in the Santa Ana watershed have been carried on for several years. Both structural and vegetative means have been used to provide flood protection. About ten authorized agencies, Federal, State, and county, have been engaged in the planning and installation of works related to flood control in this basin. Approximately $25,000,000 has been expended by Federal and local interests for flood control structures and works of improvement.

The Department of the Army, Corps of Engineers, under existing authority of the Flood Control Acts has constructed the following works of improvement: (1) Prado Dam, located on the main Santa Ana River near the Orange County line at a cost of about $9,450,000 in 1941. This structure has a design capacity of 223,000 acre-feet and will reduce the flow of the design flood from 193,000 cubic feet per second to 9,200 cubic feet per second. (2) Lytle and Cajon Creeks levees and groins, channel improvement, and by-pass were completed in 1947 at an approximate cost of $8,055,000. This system is expected to provide almost complete protection from a flood of 60,000 cubic feet per second in the overflow area between the mountains and Foothill Boulevard.

In addition, the Corps of Engineers has been authorized to construct the following works of improvement within the Santa Ana River Basin:

(1) San Antonio Dam and San Antonio and Chino Creeks channel improvements originally provided for the construction of a rolled, earth-fill dam near the mouth of San Antonio Canyon and a concrete-lined channel from the dam to the Santa Ana River at an estimated cost of $13,543,000. Subsequently, it was indicated that it may be desirable to modify the plan by enlarging the dam and eliminating the concrete channel. Although the 1938 Flood Control Act authorized appropriation of $6,500,000 for initiation and partial accomplishment of this project, modified plans have not yet been approved by the Chief of Engineers. (2) Villa Park Dam on Santiago Creek has a design capacity of 13,400 acre-feet. Estimated cost is $2,100,000.

Additional projects recommended by the Corps of Engineers 2/ include: Devil, East Twin, and Warm Creek improvements consisting of a concrete diversion channel and levee on Devil Creek, revetment of levees on upper East Twin Creek, and a concrete channel on East Twin and Warm Creeks at an estimated cost of $10,163,000. (2) Levee sections on Mill Creek near Mentone at an estimated cost of $975,000. (3) Levees on the Santa Ana River near Riverside, estimated to cost $3,160,000. (4) Levees on the San Jacinto River and Bautiste Creek near San Jacinto at an estimated cost of $3,279,000.

In summary, the Corps of Engineers (1) have constructed works of improvement for flood control amounting to $17,500,000; (2) are authorized to construct additional flood-control improvements estimated to cost $18,078,600; (3) have recommended 2/ further improvements at an estimated cost of $17,577,000, of which the Federal cost is about $14,641,000.

The Department of Agriculture has been active in the watershed through several of its bureaus concerned with land management and land treatment problems. Current programs of the Soil Conservation Service, Forest Service, Production and Marketing Administration, and the Agricultural Extension Service have resulted in many conservation and erosion control measures and practices installed on the watershed lands.

The Soil Conservation Service, cooperating with Soil Conservation Districts, provides technical assistance for application of conservation practices and measures planned in cooperation with farmers. The Service provides technical assistance for work in the field of soil erosion and flood control in the watershed as part of its activities. It is estimated the Service spent $50,000 a year for technical assistance in the Santa Ana River watershed on work directly related to the objectives of the Flood Control Act. Active conservation programs include contour farming, cover crops, range and pasture improvements, and farm and ranch ponds. Technical assistance, a Federal cost, includes necessary conservation and range condition surveys for planning and application of conservation programs. The surveys include an inventory of all land, soil, and cover types, land capability, and condition of land and cover under present use.

2/ House Document 135, 81st Congress, 1st Session, March 22, 1949, "Santa Ana River and Tributaries, California."

The Production and Marketing Administration offers assistance to farmers in the form of a payment for part of the cost of carrying out approved soil and water conservation practices. This assistance may be in the form of materials and services or cash payments. These payments are, in general, intended to defray about half the cost of the practice. In 1949 the Production and Marketing Administration made Agricultural Conservation Program payments in the watershed totaling about $82,000. Major practices in 1949 were establishing or improving permanent pasture, and application of superphosphate; other practices included dams, fencing and grazing land management.

The Agricultural Extension Service, through the County Farm Advisors, has an education program of assistance for the improvement of farms and ranches, including practices which will maintain fertility and crop yields, reduce erosion, and check excessive runoff. Federal contributions to this work have amounted to about $1,350 annually.

The Forest Service provides fire protection to about 530,282 acres of land within the watershed. This area is included in parts of three national forests--the Angeles, San Bernardino, and Cleveland. The Forest Service, under provisions of the Act of 1897 as amended, is responsible for the management and protection of this land in the public interest, including the maintenance of favorable conditions for water flow. A key function of this agency has been the protection of the Federally owned watersheds from fire. At present estimated annual Federal cost for fire prevention and control is about $168,000. The Forest Service also cooperates financially with the State of California under provisions of the Clarke-McNary Act in the protection of qualified State and private lands.

Under provisions of the 1944 Flood Control Act the Forest Service has provided emergency treatment to large burned areas where threat of flood damage existed. About 51,000 acres have been treated by sowing seed of quick-growing plants and three debris catchment structures built to provide emergency protection. A limited amount of erosion control and revegetation work has been accomplished insofar as available funds permitted. Such work included stabilization of eroding mountain meadows, treatment of road slopes, seeding and planting of denuded areas, channel clearing, and road drainage improvement.

The State of California, Department of Public Works, Division of Water Resources, has investigated the flood-control and water-conservation problems in the basin. The first investigation of this Division was reported in State Bulletin No. 19, "Santa Ana Investigation, Flood Control and Conservation," dated December 1928. Again in 1930 this Division published Bulletin No. 31, "Santa Ana River Basin, a Plan for Flood Control and Conservation of Waste Water."

Currently, the Division is restudying the basin to determine the present status of water supplies, present overdraft for each sub-basin, and the ultimate water requirements for the basin as a whole. This investigation is expected to be completed in 1950. The Department of Public Works also has assisted local interests in works of improvement for flood control and water conservation.

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The California Department of Public Works, Division of Highways, has undertaken measures on State highways to reduce erosion from road-fill slopes.

The State of California, Department of Natural Resources, Division of Forestry, has provided fire protection to the State and private lands in the watershed. The total area protected is about 369,385 acres. The Forest Service cooperates with the State in protecting about 306,000 acres of State and private land which qualify under provisions of the Clarke-McNary Act for Federal financial assistance in cooperative fire control. The area cooperatively protected under the Clarke-McNary Act includes only those lands principally privately owned and of primary timber and watershed value. Federal assistance on these lands amounted to about $50,000 in 1949, or about 22 percent of the total cost of protection provided by the State.

The California Department of Natural Resources, Division of Fish and Game, has recently planned stream improvements to provide better fish habitat conditions. These structures may also be beneficial in reducing some flood peaks. Sedimentation of the structures, however, will reduce their value for flow maintenance. The first improvements to be made in this watershed include a flow maintenance dam on Holcomb Creek at an estimated cost of $25,000; stream improvement and flow maintenance work on 14 other streams in the San Bernardino National Forest at an estimated cost of $35,000.

Six Soil Conservation Districts are wholly or partially located in the watershed. These districts are encouraging farmers to use conservation farming methods on cultivated lands, improve management of private range and forest lands and, when financially possible, to build necessary erosion and flood-control works within the districts. Technical assistance for planning and application of the program is being secured from the Soil Conservation Service.

Each of the three counties involved in this watershed has organized Flood Control Districts which have completed many works of improvement to reduce local flood damages.

The County of San Bernardino has completed about 37 miles of channel improvements including revetments, levees, bank protection, and excavation at an estimated cost of $1,343,000. The county desires additional channel improvements at an estimated cost of $4,648,000, numerous debris basins and water conservation reservoirs estimated to cost $16,195,000 and additional water spreading grounds at a cost of $1,812,000.

The County of Riverside has improved about 73 miles of channel at a cost of about $1,598,000, in addition to the construction of 7,000 feet of storm drain and a series of small check dams at a cost of $254,000. In addition, the county desires further channel improvements estimated to cost $1,606,000, diversion ditches, storm drains, and spreading grounds estimated at $478,000, four flood-control and water-conservation dams estimated to cost $6,971,000, and numerous debris basins costing about $222,000.

The County of Orange has constructed 20 miles of levee and improved 17 miles of channel at a cost of $2,310,000. The county desires additional improvements including a flood-control basin, raising the height of an existing dam and the construction of levees, bank protection works, and spreading facilities at an estimated total cost of $8,089,000.

Sources of Floodwater and Sediment.--The flood and sediment problem remaining unsolved after the complete installation of the comprehensive downstream flood-control plan is of major proportions. Floodwater and debris flows from the smaller canyons discharging directly onto urban and agricultural lands will continue to cause trouble. Unconfined mountain channels above the protection works will continue to overflow, scour, and carry huge quantities of debris which will cause severe damage to all developments located in the area. The most serious and damaging problem however, is the sedimentation of downstream protection works.

Reservoirs, debris basins, and channels in the past have filled with sediment at alarming rates throughout the southern California area. More than 11 million cubic yards of sediment were deposited in seven reservoirs on the San Gabriel watershed during the storm of March 1938 (table 9).

Table 9.--Loss in capacity of reservoirs after March 1938 flood

Reservoir	Drainage area	Capacity loss below spillway level 1/
	Square miles	Cubic yards
San Gabriel No. 1	161.58	8,391,000
San Gabriel No. 2	40.42	2,413,000
Big Dalton	4.49	143,500
San Dimas	15.92	419,000
Puddingstone Diversion	2.57	126,000
Live Oak	2.30	27,400
Thompson Creek	3.91	42,000
Total	231.19	11,561,900

1/ Los Angeles County Flood Control District report. Flood of March 2, 1938, by M. F. Burke, Hydraulic Engineer.

Table 10.--Sedimentation rates of reservoirs and debris basins, southern California area

Reservoirs and debris basins	Drainage area	Number of seasons	Debris production: Total	Debris production: Average annual
	Sq. mi.	Number	Cu. yds.	C.y./sq.mi.
West Ravine	.25	11	91,300	33,100
Fair Oaks	.21	11	57,200	24,600
Fern	.30	11	75,900	23,100
Shields	.27	9	54,000	22,300
Halls	1.06	11	256,300	22,000
Las Flores	.45	11	83,600	17,000
Dunsmuir	.84	10	136,000	16,200
Pickens	1.84	11	297,000	14,700
Eagle	.61	10	8,900	14,600
San Gabriel No. 1#	161.6	7	16,289,300	14,400
Hay	.20	10	25,000	12,300
Lincoln	.50	11	62,700	11,400
San Gabriel No. 2#	40.40	9	2,945,160	8,100
Haines	1.53	11	124,300	1/ 7,400
Puddingstone Diversion#	2.60	16	302,000	7,260
Brown Canyon	16.40	3	312,000	6,340
Santa Anita	10.80	16	1,067,900	6,180
Pacoima	27.80	15	2,182,400	5,230
Stough	1.65	6	51,600	1/ 5,200
Devils Gate	31.90	27	4,229,300	4,910
Big Tujunga	81.40	13	5,122,900	4,840
Sawpit	3.30	16	248,200	4,700
Big Dalton#	4.49	16	289,550	3,800
Nichols	.94	9	28,800	3,400
Aliso-Wilbur	8.63	4	104,400	3,000
Sierra Madre	2.39	19	1/ 123,500	2,700
Gibraltar 2/	219.00	27	13,836,400	2,340
San Dimas #	16.20	23	731,500	2,270
Puddingstone	12.30	13	353,400	2,210
Sunset	.44	17	13,800	1,800
Paradise	.96	2	3,200	1,700
Live Oak#	2.30	16	56,680	1,540
Baily	.57	1	800	1,400
Thompson Creek#	3.70	11	51,280	1,260
Rubio	1.26	3	4,200	1,100
Little Rock	68.00	22	1,395,200	930
Brand 3/	1.03	11	8,800	800
Vanaldem	1.08	1	560	500
Total	729.20		51,025,030	
Average (weighted by area and number of seasons)				4,100

1/ Estimate
2/ Includes upstream debris basins and reservoirs.
3/ Erosion control on watershed installed in 1935.
\# Located in the San Gabriel watershed.

Records maintained over a period of from 1 to 27 years on 19 reservoirs and 19 debris basins in the southern California area show rates of deposition ranging from 1,000 to 33,000 cubic yards per square mile of drainage area each year for the years of record (table 10). Since their existence these basins have caught more than 51,000,000 cubic yards of sediment. The weighted average annual rate for each square mile of tributary watershed for this 27 year period is 4,100 cubic yards. (see table 10.)

B. H. Dodge 3/ Los Angeles District, Corps of Engineers, states "It is usually more economical to provide debris storage adequate only for a single large flood and to re-excavate the basin as often as necessary to maintain design capacity. Occasionally, however, it might be found more economical to provide storage adequate for the 50-year assumed life of the structure. Factors which might lead to that conclusion would be the existence of a site where permanent debris storage could be provided at less than the cost of periodic excavation, or the necessity of utilizing a site where no feasible spoil area could be provided, such as a site within a canyon."

All of this material occupies space necessary for flood protection until removed or replaced by new storage. When sediment is deposited in flood channels the capacity of the channel is reduced. Levees can be raised or the channel can be dredged to replace the capacity lost by sedimentation. The sediment deposited in reservoirs and debris basins can either be removed, or new reservoirs can be constructed to provide the storage space required for new floods. Once the space in flood-control works is lost alternate capacity is required.

The steep, unstable mountain mass is the source of much of this flood runoff and damaging sediment. The deeply incised and steep-sided mountain stream channels are probably one of the largest sources of debris.

During the relatively dry periods the canyons and mountain tributaries accumulate channel deposits as a result of normal erosional processes. In certain areas, this normal rate is accelerated by man's activity. Most of this accumulated waste material remains in the channel ready to be flushed out by the first heavy runoff-producing storm.

A large part of the mass movement of debris occurs during these heavy rainfall and high streamflow periods. At such times the mountain floodwaters rush down the steep channels, scouring the channel of accumulated debris. Channel banks are undercut to leave great quantities of soil and rock suspended with insufficient base support. As a result, huge slides and land slumps frequently develop. Undermined trees topple into the stream, outcropping rocks and boulders, or masses of eroded soil may temporarily dam the channel which when waters break through cause momentary surges entirely out of proportion to the rainfall

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3/ B. H. Dodge, "Design and Operation of Debris Basins," Proceedings of the Federal Interagency Sedimentation Conference, January 1948.

intensities. These same obstructions also cause the flow to meander violently from side to side, eating into stream banks incapable of withstanding the destructive force of the debris-laden flows. Trees and other vegetation that have aided in holding the side slopes in place are now ineffective in protecting the banks from being undermined. Repetition of this process over a period of years gradually eats away whole mountain slopes.

Field surveys of many mountain channels throughout southern California in 1939 and 1940 showed that, in most channels, material available for transport is almost unlimited. A flood of 1938 proportions occurring in 1939 would have produced debris movements in many canyons as large as or larger than that which occurred in 1938. Field estimates of the quantity of channel bed material showed a maximum of 1,000,000 cubic yards per mile of length in the lower reaches of the larger channels. Gradients in these sections are sufficient to develop discharge velocities capable of transporting large boulders during major floods. During moderate flood stages sufficient material of proper grading is readily available in the channel beds and adjacent side slopes to completely satisfy the carrying capacity of these flows.

Mountain wild fires and soil disturbances from road construction have added greatly to runoff and sediment. When the mountain land is laid bare by fires the infiltration capacity of the soil is greatly reduced. Surface runoff is increased and large quantities of soil are moved by even moderately intense storms. Where fires occur repeatedly, as is usual in the lower elevations, soil is lost faster than it can form. Recovery of the vegetation to optimum density is retarded and runoff is increased for long periods.

On the San Gabriel watershed approximately 70 percent of the area under fire protection has been burned one or more times during the past 50 years alone. The gross area of the individual burns, during this time, has been approximately 163,000 acres. How often and how much of the cover has been burned during the past century is not known exactly. But wild fires must have raged because early attempts were made to convert the steep mountain land to pasture. Areas burned in individual years vary greatly. This is illustrated in table 11. For instance, in 1919, 67,500 acres burned, in 1924, 40,600 acres burned, but in 1936 only 154 acres burned.

The average annual burn is greatest at the lower elevations where the highly inflammable chaparral and chamise abound. They are the areas of most direct threat to the valley land. Here the average annual burn is 1,100 acres or 0.9 percent of the burnable areas. In the less hazardous high back country the annual rate is 0.25 percent or 138 acres and in the valley hills it is .70 percent or 460 acres.

Under present control conditions individual fires may denude single areas as large as 25,000 acres.

Table 11.--Watershed areas burned in San Gabriel River basin 1/ 1896 to 1946

Year	Area burned	Year	Area burned
	Acres		Acres
1896	7,366	1926	642
1898	1,741	1927	2,151
1900	7,130	1928	1,357
1903	3,315	1929	3,294
1906	640	1930	397
1909	410	1932	525
1911	282	1933	781
1912	13,312	1935	262
1913	570	1936	154
1916	774	1937	928
1917	371	1938	1,551
1918	160	1939	1,536
1919	67,497	1942	2/ 307
1922	230	1943	3,090
1923	1,030	1944	120
1924	40,647	1946	255
		Total	3/ 162,825

1/ Includes 243,168 acres in the fire protection zone.

2/ Burn history for Los Angeles County portion not included for the period 1942-46.

3/ Sixty-seven percent of the protected area denuded.

Mountain road construction has added greatly to the debris problem. Blasting has loosened the shattered rock to create recurrent slides which have eaten headward up the mountain slopes. Through-fills constructed to bridge drainage ways and long, steep overcast slopes resulting from side hill construction have created new and extensive areas of raw, eroding soil and rock waste. Inadequate or faulty drainage facilities have accelerated runoff and erosion problems on many miles of existing mountain roads. The collection, concentration, and disposal of storm waters on impervious road surfaces has started new gullies in the mountain side.

Such disturbances, either by fire or construction, have accelerated the normal process of erosion as well as altered the normal hydrologic characteristics of the naturally unstable mountain area.

Agricultural use of the cones at the foot of the mountains, brush fires, overgrazing, and cultivation of the valley hills are the major runoff and sediment contributors in the valley areas.

The alluvial cones at the foot of the mountains are not only the recepients of damage from the mountain and foothill streams but also the source of damages on lower land. Water from high intensity rains on bare cultivated cone land collects and rushes down along the numerous depressions toward the stream channels. On its way it picks up large amounts of topsoil, gravel, and rocks. It undermines trees in sloping groves and destroys irrigation lines. As it approaches a channel or flatter terrain it drops its load to spread over roads, orchards, lawns, and gardens, and often deposits debris many feet deep.

Flows from the valley hills have similar effects. Quite frequently small channels have formed on the hillsides but do not continue through the level land. The channels either have been obliterated by the plow or have been prevented from forming by the large amount of silt carried from the hills.

Heavy use of grazing land and improper cropland practices have effects comparable to those of burned watersheds. While not as spectacular, such effects are none the less important.

It is toward the solution of these problems--mountain and hill fires, unstable mountain and valley channels, and unwise agricultural use of cone, hill, and valley land--that the Department of Agriculture's flood-control activities are directed.

UNITED STATES DEPARTMENT OF AGRICULTURE

APPENDIX 2

HYDROLOGIC ANALYSIS OF THE FLOOD PROBLEM

San Gabriel and Santa Ana River Watersheds, California

To accompany report on survey, flood control,
San Gabriel and Santa Ana River Watersheds, California

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HYDROLOGIC ANALYSIS OF THE FLOOD PROBLEM

San Gabriel and Santa Ana River Watersheds, California

In the development and evaluation of flood prevention and control activities, information on the size and number of floods to be expected is required. Of equal importance, however, is a means for estimating the effects of flood-control measures on flood size. Past floods and past storms furnish the chief clue to both the size and number of future floods that may be expected.

If flood discharges from a watershed had been measured for several hundred years, and if watersheds had been and would remain static, then frequency of expected discharges could be rather easily determined. However, for most watersheds not even an approximation of such conditions exists. Watersheds have been changing and are continuing to change. Discharge records are short and have been measured under varying watershed conditions. Therefore, it has been necessary to study flood "causes": to determine how meteorological events combine to produce discharges and how watershed conditions and changes in watershed conditions affect discharges. The results of these studies permit extension and adjustment of past short-term discharge records before making estimates of discharge frequency and provide a basis for estimating the changes that treatment of the watershed can bring about in future flood frequencies.

A frequency of maximum or peak discharges is needed in order to estimate annual damages. The effect of land management on frequency of discharges is required to evaluate the damage reduction from changes in cover.

Flood causes may be grouped into two broad categories: the precipitation characteristics and the physical characteristics of the watershed which govern the disposition of the precipitation.

Precipitation Characteristics.- Most of the storms in this region are associated with the extra-tropical cyclones of North Pacific origin. During the winter months these storms move south over the ocean, being warmed and picking up moisture en route until they are forced landward by the Pacific high pressure zone. As the storms reach land they meet the cold air masses and the mountains which force the moisture-laden air to rise and produce precipitation over much of southern California, which is often torrential in nature. Thunderstorms which produce high intensities locally occasionally occur either in connection with the general winter storms or independent of them.

Most of the precipitation received in the drainage is in the form of rain. Some snowfall occurs in the high mountains, but snow melt, in this area, is generally considered to have little effect upon the flood flows of the main drainage system.

The distribution of the precipitation throughout time is important in influencing floods. The short-time intensities of precipitation are a critical element in influencing the magnitude of the peak discharge of the individual flood. At the other extreme, the long-time cycles of precipitation influence the frequency of occurrence of flood events.

In this area the average annual precipitation varies widely, chiefly with elevation, from as little as 15 inches in the lower flood plain areas to about 20 inches at the foot of the mountains and an average of approximately 33 inches in the mountain watersheds--with over 40 inches at some of the mountain peaks. For individual years the precipitation has varied from as little as one-fourth to as much as two times the average annual. Pronounced cycles of wetness and dryness have been shown by taking a ten-year moving average of the annual wetness, figure 1.

The distribution of precipitation by seasons within each year varies widely. Because during the summer time the Pacific high pressure zone moves inland over the southwestern United States, storms are effectively deflected from the area and summer precipitation is practically zero. Thus about 90 percent of the annual precipitation occurs during the six-month period from November to April. For every month except November of this six-month winter period major flood-producing storms have been recorded. This may best be shown from the precipitation characteristics of some major historic floods which have been worked up from data collected by the Corps of Engineers, Department of the Army, as shown in table 1.

The amount of high intensity precipitation and the wetness of the watershed are of primary importance in influencing the size of floods; however, poor watershed cover conditions may be responsible for producing major floods from moderate storms. This is illustrated by the floods of 1884. Newspaper accounts reported large fires in the mountains in the years just prior to these floods. It would appear that denudation of the watersheds by these fires was responsible for putting these storms, which had relatively low precipitation, in the major flood-producing class.

Table 1.- Precipitation characteristics of some major storms--mean areal depths--San Gabriel watershed above Whittier Narrows dam site

Storm	Precipitation during: 3 hours	Precipitation during: 24 hours	Precipitation during: 72 hours	10-day antecedent precipitation
	Inches	Inches	Inches	Inches
February 14-18, 1884	--	5.9	9.9	5.0
March 3-9, 1884	--	5.4	12.4	0.0
December 21-26, 1889	--	5.9	11.0	7.1
February 17-22, 1914	1.6	7.0	16.3	1.0
January 14-19, 1916	1.9	9.7	16.6	2.7
December 17-23, 1921	2.4	12.6	21.4	2.7
April 4-9, 1926	1.5	7.0	11.0	0.3
February 12-18, 1927	1.4	8.5	15.9	4.6
January 1-2, 1934	1.4	8.7	11.5	0.1
Feb. 27 - March 3, 1938	3.5	12.3	19.2	5.2
January 21-24, 1943	3.5	18.0	26.5	0.4

Watershed Characteristics.- The characteristics of the watersheds which influence floods are the result of the action of the environmental factors of climate, vegetation, time, and past use on the geologic masses resulting from the mountain-forming processes. The major upthrust of this mountain group is said to have occurred some million years ago during Pleistocene times. The masses of igneous and metamorphic rocks were highly faulted and fractured during uplift, and along the major faults, steep-sided canyons have developed. The slopes of the canyon side walls average, for whole watersheds, from 36 to 49 percent. Deep fracturing is largely responsible for the high water storage capacities which have been reported for these watersheds. General youthfulness of the mountains, the climatic characteristic of torrential precipitation occurring in the winter months, the hot, dry summer months, and the recurrent fires are reflected in the soils and vegetation found on the mountains. The soils are shallow, mostly less than 3 feet in depth, coarse-textured, and have little profile development. The vegetation which these soils support is characterized by those species which are able to withstand, in one way or another, recurrent fires and various degrees of soil and atmospheric drought. At the lower elevations where precipitation is light, on south and west exposures where direct heating is greatest, and at those places where recurrent fires have resulted in the greatest soil loss, drought is most severe and only sparse chamise

and sage cover types exist. On progressively less dry sites are found the mixed chaparral, oak-chaparral, and coniferous types. Although the physiological adaptations which the vegetation species have made to fire indicate that during early times lightning fires and possibly some fires caused by the aborigines played a part in the vegetation formation of this area, the most drastic influence has been the advent of the white man. Fires have been accelerated and some areas burned and reburned. There is little doubt that the watersheds are now different than they were: loss of soil following the fires, stream channels choked with debris, and generally dryer sites have been the result. Thus these watersheds have probably deteriorated in their capacities to resist floods since the early historical floods occurred. And, except where improved fire protection will reduce the coincidence of large storms occurring on fresh large burns, future floods may be expected to be greater than floods of the distant past. However, if, during some future interval of time, the watersheds receive improved protection for a long period, then soil building can occur, maximum cover density increase, and peak discharges be reduced. If, on the other hand, future misuse is permitted, more drought tolerant, less dense vegetation may be expected to occupy the area. Under such conditions cover will become even less dense, cover changes will be smaller as the result of fire and recovery from fire, and a sustained higher level of peak discharges may be expected to result.

Runoff.- The discharge records for the streams in this basin are numerous; more than 65 gaging stations have been operated at various times. The longest records of peak discharges are for the San Gabriel at the Azusa gaging station and for the Santa Ana River at Mentone from which maximum yearly peak discharges have been reported since 1914. Records from a few other canyons start in 1916, but the majority of the stations have been operating only since about 1930. The maximum recorded peak discharges and other pertinent data for a few representative gaging points are given in table 2. The records of discharges from watersheds, when corrected for the watershed burn conditions under which they occurred and extended on the basis of long-time precipitation records, permit estimation of flood frequency and sedimentation from the watershed units.

Table 2.- Maximum discharges and sedimentation into reservoirs in and adjacent to San Gabriel River watershed

Watershed	Area	Period of record	Maximum discharge during period	Average annual sedimentation during period
	Sq.mi.		C.f.s./sq. mi.	C.y./sq. mi.
Dalton	4.5	Aug. 1929-Oct. 1945	295	3,800
Live Oak	2.3	Nov. 1922-May 1938	147	1,540
Puddingstone	2.6	July 1928-Sept. 1944	1/ 310	7,260
Puddingstone	12.3	Jan. 1928-Jan. 1941	2/ 160	2,210
San Gabriel #1	161.6	Oct. 1937-July 1944	3/ 446	14,400
San Gabriel #2	40.4	Jan. 1936-Jan. 1945	612	8,100
San Dimas	15.9	Oct. 1921-Oct. 1944	310	2,270
Santa Anita 4/	10.8	March 1928-May 1944	496	6,180
Sawpit 4/	3.3	June 1927-Dec. 1943	306	4,700
Thompson	3.7	Oct. 1932-Jan. 1943	157	1,260

1/ For 18.5 square-mile area.
2/ For 33.1 square-mile area.
3/ For 202.0 square-mile area.
4/ Located in the adjoining Los Angeles River watershed.

Sedimentation.- Records of sedimentation are available for eight reservoirs within the basins and for several reservoirs near the area, table 2. In most instances measurements of debris catches in these reservoirs were not obtained before 1928; and, since yearly measurements were not always made, the record of sedimentation for the area is still somewhat fragmentary. Nevertheless, records are much better than are usually available for watersheds. Relatively good estimates can be made of sedimentation rates and the effects of land treatment on those rates when related to discharge and watershed cover conditions.

Hydrologic Analysis.- Frequencies of peak discharges and sedimentation were estimated for the various drainages and subdrainages for various densities of vegetation cover. By multiple regression analyses of the data, equations were obtained which gave the independent effects on peak discharges and sedimentation of some storm and watershed variables. The equations and the partial regression coefficients of the equations were used:

(1) To convert to a comparable basis of forest conditions the discharges which had been measured under a variety of watershed cover conditions so that the discharges could be used in a frequency analysis;

(2) To extend the existing records of discharges by relationship of discharges to the long-time precipitation records;

(3) To aid in estimating discharges for watersheds for which no measurements had been made;

(4) To convert the frequency of discharges under one condition of watershed cover to the expected frequency under other conditions;

(5) To estimate the effect of a large burn in a given watershed on the discharges and sedimentation due to a major flood-producing storm, which might serve as an aid in designing flood-control structures.

The analysis made use of considerable basic data collected over a period of years by interested agencies. Peak discharges have been measured by the U. S. Geological Survey and by the Los Angeles County Flood Control District for many of the streams in the area. Sedimentation measurements have been made by the Los Angeles County Flood Control District, the U. S. Forest Service, and the Soil Conservation Service. Precipitation measurements and compilations have been made by the U. S. Weather Bureau and other interested agencies. Fire histories and cover type maps for the mountain areas have been made by the U. S. Forest Service. Recently completed work by J. S. Horton, U. S. Forest Service, on the relation of cover density to cover age, cover type, and geologic origin of the parent material of the soil permits rapid approximations of the forest cover density from compilations of cover types, cover ages, and geology. Aerial photographs and U. S. Geological Survey topographic maps furnish basic data on areas, physiography, vegetation, and other land features. The first step was to determine the relation of flood characteristics to storm and watershed variables.

Flood Characteristics Studied.- Two flood characteristics were studied--the peak discharge from watersheds during storms and the annual sedimentation in reservoirs. Peak discharges from the various watersheds were important because they were related to the impact and inundation damages which the storm produced. The sedimentation in reservoirs and debris basins was important because of the reduction in storage capacity. In addition, sedimentation was the best index of total erosion from the watersheds which is related to watershed deterioration, to bulking of flood flows with debris, and to other damages such as deposition of debris in water spreading grounds and on roads.

Method of Analysis.- A statistical approach was used in determining the relationship of peak discharges and sedimentation to storm and watershed variables. The analysis was made on a watershed basis to avoid the difficulties encountered in applying small plot data. Although similar plots may be found, similar watersheds are rare. Therefore, the effects of watershed differences had to be evaluated by a statistical tool, multiple

regression analysis.1/ This method permitted the quantitative determination of the independent effect of each of several independent variables on a dependent variable. It gave a measure of the significance of each of the effects, the probable range of error or variation in the individual effects, and the error in the estimate of a single value of the dependent variable from the associated values of independent variables acting together. The results are expressed in the form of an equation which is compact in form and easy to use.

The Variables Studied.- Three precipitation variables, six watershed variables, and two joint variables were tested. See table 3 for unit and ranges in the variables.

A storm was defined as a period of precipitation unbroken by lapses of greater than 24 hours. The storm and its characteristics were assumed to be representable by the maximum 24-hour and maximum 1-hour intensity during the storm. The pre-storm watershed wetness was represented by the total precipitation occurring during the 21-day period antecedent to the maximum 24-hour precipitation of the storm.

The area of the watershed was used to give a measure of the effects of watershed size alone on peak discharges and to avoid attributing effects to other variables, which were correlated with areal effects.

The cover density was used as the best expression of cover effects, and it was determined for the actual watershed condition for each storm by applying the cover density-cover age relationships developed by the U. S. Forest Service (table 4); cover age was taken from fire history maps. The other watershed variables tested proved statistically nonsignificant.

1/ Illustrations of the use of the method may be found in papers by: Zinzg, A. W., 1943 Proc. Soil Sci. Soc. Amer. 8:109-111; Anderson, H. W., 1946 Trans. Amer. Geoph. Union, 27(_):833-870; Anderson, H. W., 1947 Jour. of Forestry, 45(2):94-101; Gottschalk, L. C., 1947 Trans. Amer. Geoph. Union 28(4):621-625.

Table 3.- Definition of variables tested

Symbol	Variable	Units	Range
Q	Momentary peak discharge from watershed during the storm	C.f.s.	5-90,000
e	Sedimentation in reservoir during a single year	Ac.ft./sq. mi.	0.3-36.0
q	Maximum yearly peak discharge	C.f.s./sq. mi.	10-550
A	Area of the watershed	Sq.mi.	1.5-202.2
P_{24}	Maximum 24-hour precipitation for the watershed during the storm	Inches	1.5-20.0
P_1	Maximum 1-hour precipitation for the watershed during the storm	Inches	0.2-2.1
aP	21-day precipitation antecedent to the maximum 24-hour for the storm	Inches	1.0-23.0
C	Cover density on the watershed	Percent	2.0-72.4
Ch	Area of main channel of the watershed	Ac./sq.mi.	1.7-9.7
LAG	Corps of Engineers, Dept. of the Army, half-time for runoff	Hours	0.4-3.0
gr	Maximum retention of watershed (1940-41) corrected for fire and precipitation, based on geology	Inches x sq.mi.	36-1,745
L	Length of main channel	Miles	1.9-22.0
P_{24}/C	Joint variable of P_{24} and C	Inches/percent	
$P_{24}aP$	Joint variable of P_{24} and aP	Inches^2	
C/A	Joint variable of C and A	Percent/sq. mi.	
F	Area of old fires occurring between 1878 and 1922	Acres	128-67,800

Table 4.- Vegetation density recovery rates following fire--by cover types for various geologic origins of soil parent materials

Cover type	Geology	Minimum cover density	Maximum cover density	Recovery rate (k) 1/
Oak chaparral	Metamorphic	0	90	0.156
	Igneous	0	80	0.139
	Sedimentary	0	65	0.152
Pure chamise and chamise sage	Metamorphic	0	60	0.110
	Sedimentary & igneous	0	50	0.058
	Anorthosite	0	40	0.037
Chamise-manzanita and chaparral	Metamorphic	0	80	0.123
	Igneous	0	75	0.116
	Sedimentary	0	65	0.112
High elevation chaparral	Metamorphic	0	80	0.138
	Sedimentary & igneous	0	70	0.143
Oak woodland (Quercus chrysolepis)	All	0	90	0.263
Oak woodland (Quercus agrifolia)	All	30	40	0.105
Desert chamise and chaparral	Metemorphic	0	65	0.100
	Igneous	0	60	0.094
	Sedimentary	0	30	0.080
Coastal sage	All	0	40	0.153
Desert sage	All	0	30	0.100
Semidesert chaparral	All	0	30	0.051
Pinon juniper	All	10	25	0.074
Timberland chaparral	All	0	50	0.054
Semibarren	Metamorphic	0	20	0.093
	Sedimentary & igneous	0	20	0.053

1/ Vegetation density recovery following fire, where if C_t is the cover density "t" years after a fire, C_{Min} is the minimum cover density after a fire, C_{Max} is the maximum change in cover density attained in about 40 years after a fire, t is the years after a fire, k is the constant representing the recovery rate, and e is the base of the natural logarithms; then C_t may be determined from the growth equation $C_t = C_{Min} + C_{Max}(1-e^{-kt})$.

Results of Peak Discharge Study.- The relation of the peak discharge to storm and watershed variables was determined by multiple correlation and regression analysis of 127 data from 27 watersheds. 2/ The watersheds studied varied in area from less than a square mile to 202 square miles and were located along an 80-mile stretch of the south-facing slope of the Sierra Madre and San Bernardino Mountains. The discharge data analyzed ranged in time from the May 21, 1921, storm to the February 22, 1944, storm.

After elimination of statistically nonsignificant variables, the best estimate of peak discharges was obtained from the following equation:

$$\text{Log } Q = 1.101 + 1.106 \log A + 0.521 \log aP + 1.179 \log P_{24} + 1.006 \log P_1 - 0.973 \log C$$

The standard error of estimate was ± 0.283 and the correlation coefficient was .950, the standard errors of the various partial regression coefficients were: for log A, ± 0.054; for log aP, ± 0.067; for log P_{24}, ± 0.288; for log P_1, ± 0.243; and for log C, ± 0.154. All the variables are highly significant.

Although the 1-hour precipitation intensity was highly significant and improved the estimation of individual discharges it could not be used in the frequency analysis because of the lack of a long-time record of 1-hour intensities in the mountains and insufficient correlation between 1-hour intensities in the mountains and at Los Angeles, where a long-time record was available. However, shorter intensities are highly correlated with the maximum 24-hour precipitation for a storm. Therefore, a satisfactory estimate of frequencies of discharges may be made without the 1-hour intensity as shown in the following equation:

$$\text{Log } Q = 1.2934 + 1.0822 \log A + 1.8705 \log P_{24} + 0.4737 \log aP - 0.8520 \log C$$

The standard error of estimate was $\pm .301$ log units, the multiple correlation coefficient was .942, and the standard errors of the various partial regression coefficients were: for log A, ± 0.057; for log P_{24}, ± 0.099; for log aP, ± 0.070; and for log C, ± 0.161. All the variables were highly significant. The regression coefficients in this equation represent valid estimates of the independent effects of the variables on peak discharge; therefore, any part or parts of the equation may be used independently.

The above equation was used to estimate peak discharges for watersheds for which none were available. In addition, it was used to extend the period of discharge records on the basis of the long-time rainfall records. Finally, it served as a basis for estimating the effects on peak discharge which result in changes in cover density.

2/ Basic data are given in an article in Trans. Amer. Geophys. Union; 30(4): 567-584, 1949.

In order to check the validity of the functions used, other variables were tried. Among these was the joint variable log P_{24}/log C which tested whether the logarithmic cover density effect varied with storm size. This variable proved to be statistically nonsignificant; so it was concluded that the log C effect is linear for all values of P_{24} encountered. A joint variable of log C/log A was used to test whether the cover effect varied with watershed size. No such effect was detectable. A possible joint effect of log P_{24} and log aP was tested but also found to be statistically nonsignificant. The equation was, therefore, considered suitable for use in determining peak discharge frequencies and cover effects on flood frequencies.

Application of the Equation.- A long-time frequency of maximum 24-hour and 21-day antecedent precipitation is basic to the application of the equation to extend the record existing discharge data or estimated discharges from watersheds where no discharge data are available.

Since no long-time record of precipitation for mountain watersheds is available, it was necessary to extend the precipitation records for those watersheds on the basis of their relationship to the Los Angeles stations, where a 69-year record was available. The method of such extension is given here for one watershed--Big Santa Anita--which was found to be suitable as a basic mountain watershed because no fires had occurred in it since 1900. Further, a 30-year record of precipitation at a headwaters station--Mt. Wilson--was available as well as a stream gaging station at its mouth. The precipitation record for Big Santa Anita was extended to a 69-year record by its relationship to Los Angeles.

The average precipitation for Big Santa Anita watershed has been found to be that at Mt. Wilson times a factor of 0.98. The 30-year record of precipitation for Big Santa Anita watershed was extended to a 69-year record by means of four relationships: (1) maximum daily precipitation at Big Santa Anita to that at Los Angeles for individual storms of various sizes; (2) the 21-day antecedent precipitation for the two areas: (3) number of storms for various storm sizes for the two areas; and (4) maximum daily related to maximum 24-hour precipitation for various sizes of maximum dailies at Big Santa Anita. Application of these relationships resulted in the extended record of maximum daily and coincident 21-day antecedent precipitation as given in table 5.

Peak discharge frequencies were obtained from the precipitation record, the discharge equation, and the record of observed peak discharges for Big Santa Anita watershed. The following steps were involved: (1) The discharge equation was used to calculate the peak discharges for all of the storms of the long-time precipitation record given in table 5. (The actual storm sizes were used for the large events and the group means of table 5 for the small events.) (2) For those storms occurring during the period of discharge record (October 1, 1916, to April 30, 1946, numbers indicated by figures in parenthesis, table 5) the calculated discharge

was compared with the observed peak discharge for the storm, figure 2. (3) On the basis of the relationship of the calculated peak discharges to the observed peak discharges, the calculated discharges for the period of no observed discharges were corrected. (4) The observed peak discharges plus the corrected calculated peak discharges constitute a 69-year record of discharges from which the frequency was obtained.

Table 5.- Maximum daily precipitation of storms and associated 21-day antecedent precipitation for Big Santa Anita watershed for 69-year period, Oct.29, 1877, to April 6, 1946

(Numbers in parenthesis are for period Oct.1, 1916, to April 30, 1946)

Maximum daily precipitation in inches	21-day antecedent precipitation--inches					
	<2.00	2.00-3.99	4.00-7.99	8.00-15.99	16.00-31.99	>31.99
0.02-0.99	765(325)	147(68)	120(50)	74(24)	32 (12)	1 (1)
1.00-1.99	130(51)	45(26)	35(17)	31(13)	6 (2)	
2.00-2.99	38(16)	21(10)	25(17)	14(4)	8 (5)	
3.00-3.99	22(8)	7(3)	9(5)	11(3)	2 (1)	
4.00-4.99	7(5)	9(3)	9(3)	5(4)	3 (2)	1 (0)
5.00-5.99		3(1)	3(2)	3(2)	2 (0)	
6.00-6.99	2(1)	2(0)	3(1)	1(1)		
7.00-7.99	1(0)			1(1)		
8.00-8.99	3(1)	1(0)				
9.00-9.99				1(1)		
10.00-10.99	3(0)			1(0)		
11.00-11.99	1(1)				1 (1)	
12.00-12.99						
13.00-13.99			1(0)			
14.00-14.99						
15.00-15.99	1(1)					
Totals	973	235	205	142	54	2
Grand total 1,611						

The relationship established in figure 2 constituted a correction of the calculated discharges for nearly all the individual characteristics of the watershed which affected the discharges. That is, the discharges are corrected for the effects of the watershed's geology, shape, etc., for errors in measuring watershed precipitation, and determining snow effects. In addition, the independent effect of cover changes, obtained by isolating the effect from a study of a large number of watersheds, was retained. Although there is considerable dispersion about the trend line relationship of figure 2, the estimate of the frequency for this short period is satisfactory. Figure 3 shows a favorable comparison of the frequency of observed discharges and frequency of corrected calculated discharges for the same period. Therefore, the extended record of peak discharges for Big Santa Anita watershed was arranged and plotted by the Duration Curve Method in figure 4 to develop the frequency curve. Repetition of the analysis would give peak discharge frequencies for other watersheds in the basin. Generally, other watersheds in the basin experienced the same storms and had some records of peak discharges, which permitted comparison with the peak discharges of Big Santa Anita for the same storms to obtain the peak discharge frequency relationship of any subwatershed. First, all the peak discharges of the watersheds were brought to a common basis as expected for a 40-year-old cover density by the cover-peak-discharge relationship obtained in the equation. The average cover density of the watershed at the time of the peak discharges was obtained by weighting areas of cover density. Areas of cover ages, cover types, and geology were applied to curves developed from the equations of table 4.

Correction of peak discharge was based on cover-density-peak-discharge relationship which is a part of the discharge equation. This is illustrated by correcting the peak discharge of the February 16, 1927, storm for City Creek watershed following the 1922 fire:

Actual peak discharge = 1,930 c.f.s.
Actual cover density = 48.4 percent
Cover density 40-year-old = 75.0 percent
Change in log Q = -0.852 [log (75.0/48.4)]
Log Q(40-year-old cover) = log 1,930 - 0.1621 = 3.1235
Q(40-year-old cover) = 1,330 c.f.s.

This 1,330 c.f.s. discharge rather than 1,930 c.f.s. was used in the frequency analysis. Similar adjustments were made for all watersheds and all discharges were adjusted before being used. The magnitude of these adjustments varied widely between watersheds: the maximum reduction applied to observed discharges was as little as four percent for Big Santa Anita, and as great as 89 percent for Fish Canyon the first year after a nearly complete burn. By use of these adjustments, the discharge records for each watershed were transformed to a single comparable watershed condition.

The method of obtaining peak discharge frequency is illustrated by the determination for the watershed above San Gabriel No. 2 dam which has a drainage area of 40.4 square miles. Each observed peak discharge

measurement at the gaging station for the 15-year period was adjusted to an assumed constant cover density of 69.1 percent, or a 40-year-old cover. The discharge record was extended to a 69-year period by using Big Santa Anita as a basis and the relationship of its discharges to those of San Gabriel No. 2 for the same storms, as shown in figure 5.

The resultant frequency of maximum yearly discharges for San Gabriel No. 2 for a 40-year-old cover condition is shown in figure 6.

Discharges for other cover conditions were obtained by the cover-discharge relationship of the equation. Discharges expected for the watershed above San Gabriel dam No. 2 under the present fire protection level of 0.77 percent average annual burn (cover density 66.2) were obtained by multiplying the discharges for the 40-year-old cover condition by a factor of 1.037. Under a complete cover improvement program and fire protection (cover density 68.4), the peak discharge frequency was obtained by multiplying the discharges for the 40-year-old cover by a factor of 1.007. The effect on peak discharges of a large burn (say 4,700-acre fire) equal to one-fourth of the high fire hazard brush zone in the drainage above San Gabriel dam No. 2 is to multiply the size of the peak discharges by 1.187.

Using the same technique, frequency of peak discharges was obtained for all watershed units. These discharges are summarized in tables 6 and 7 to permit duplication of the frequency curves for various watershed conditions.

Table 6.- Peak discharges for subwatersheds of the San Gabriel River watershed

Subwatershed	Area	Maximum yearly peak discharge for 40-year-old forest cover for selected frequency points 1/: 1	5	20	50	Factors to convert discharges 2/: Present 3/	With reduced fires 4/	Large burn 5/	Area of large burn 6/
	Sq.mi.	C.f.s.	C.f.s.	C.f.s.	C.f.s.				Acres
Big Dalton 7/	4.5	1,070	490	163	44	1.065	1.012	1.272	710
Big Dalton 8/	2.7	660	330	150	46	1.058	1.012	1.269	425
Fish	6.5	2,500	1,500	490	220	1.057	1.012	1.278	1,040
Little Dalton	3.0	730	330	150	74	1.050	1.013	1.278	530
Live Oak	2.3	290	160	83	42	1.078	1.016	1.234	320
Puddingstone 7/	2.6	4,600	2,000	680	230	1.053	1.010	1.260	390
Puddingstone 8/	12.3	4,900	2,300	1,200	650	1.078	1.016	1.090	770
Roberts	6.4	2,300	1,200	470	160	1.057	1.012	1.278	1,000
San Dimas	15.9	4,200	1,700	680	240	1.051	1.012	1.277	2,500
San Gabriel No.1	202.0	79,000	37,000	13,000	4,000	1.022	1.007	1.168	21,600
San Gabriel No.2	40.4	24,000	12,000	4,000	1,500	1.037	1.007	1.187	4,700
San Jose	80.2	12,300	7,700	4,200	1,900	1.027	1.005	1.072	4,000
Thompson	3.9	520	270	145	86	1.078	1.016	1.272	610
Walnut	26.2	8,200	5,800	3,600	1,900	1.022	1.007	1.070	1,290

1/ Number of times in 100 years peak discharges equalled or exceeded.

2/ Discharges for 40-year-old cover times factor converts discharges to other conditions.

3/ Factor for present watershed cover condition with present fire protection level; burn percent given in column 3, table 7.

4/ Factor for watershed cover conditions expected if average annual burn is reduced to 0.2 percent.

5/ Factor for first year after a large burn which equals 1/4 of the brush area in the watershed.

6/ One-fourth of brush area burned; larger burns are probable in small watersheds.

7/ Above diversion.

8/ Above dam.

Table 7.--Peak discharges for subwatersheds

Drainage	Drainage area	Maximum yearly peak discharge for 40-year-old cover for selected frequency points 1/				Discharge conversion factors for different watershed conditions 2/			Probable area of large burn 6/
		1	5	20	50	Without program 3/	With program 4/	With large burn 5/	
	Sq.mi.	C.f.s.	C.f.s.	C.f.s.	C.f.s.				Acres
San Antonio	26.7	12,100	3,300	620	160	1.056	1.007	1.157	2,430
Cucamonga	10.1	9,200	2,600	790	185	1.074	1.009	1.250	1,470
Day	4.8	2,800	1,030	230	120	1.081	1.011	1.212	600
Deer	3.7	3,000	910	270	90	1.089	1.011	1.195	420
E.Etiwanda	3.1	1,210	530	120	60	1.082	1.010	1.275	500
San Sevaine	1.9	720	307	100	37	1.088	1.010	1.147	160
Lytle	47.9	20,000	6,700	1,530	430	1.061	1.010	1.127	3,520
Upper Cajon	40.9	14,100	8,500	2,250	640	1.118	1.016	1.264	6,290
Lone Pine	15.3	5,000	1,400	730	130	1.100	1.014	1.261	2,320
Devil	6.2	2,600	580	125	57	1.089	1.014	1.270	970
Strawberry	8.6	3,050	1,000	280	110	1.062	1.008	1.270	1,350
Sycamore near Devil	2.2	920	210	44	20	1.089	1.014	1.270	345
Waterman	4.6	1,950	770	270	112	1.076	1.008	1.267	720
Little Sand	1.5	400	140	35	14	1.157	1.017	1.275	240
City	19.7	5,600	3,600	1,050	290	1.094	1.010	1.275	3,150
Plunge	16.9	4,350	1,900	740	310	1.095	1.010	1.275	2,700
Santa Ana near Mentone	144.0	53,000	14,000	4,000	1,900	1.045	1.008	1.148	12,300
San Timoteo	118.0	6,800	3,300	1,340	470	1.125	1.025	1.148	10,100
Bautiste	54.5	21,400	7,600	2,500	1,100	1.130	1.013	1.261	8,300
W.of Noble	1.9	316	135	55	20	--	--	--	0
Wilson-Potato	24.6	2,040	1,000	400	140	1.125	1.025	1.213	3,050
Edgar--Noble	22.8	5,900	2,500	1,010	360	1.125	1.025	1.205	2,700
Live Oak	23.4	1,970	960	390	135	1.125	1.025	1.164	2,230
Reche	11.6	520	250	100	39	1.259	1.065	1.200	1,350
San Jacinto	140.0	53,000	14,500	2,600	860	1.122	1.015	1.160	13,000
Leach	2.6	320	140	30	13	1.122	1.1013	1.197	300
Santa Ana near Prado	1,465.0	90,000	12,600	4,600	2,400	1.080	1.010	1.165	140,000
Main--Eagle	4.3	540	260	75	22	1.122	1.1013	1.197	490

Continued

Table 7.--Peak discharges for subwatersheds - contd.

Drainage	Drainage area	Maximum yearly peak discharge for 40-year-old cover for selected frequency points 1/: 1	5	20	40	Discharge conversion factors for different watershed conditions 2/: Without program 3/	With program 4/	With large burn 5/	Probable area of large burn 6/
	Sq.mi.	C.f.s.	C.f.s.	C.f.s.	C.f.s.				Acres
Mill	43.2	16,100	3,000	870	350	1.052	1.007	1.153	3,800
Olive	5.1	560	270	110	40	1.125	1.025	1.162	480
Potrero	31.0	13,000	4,800	1,480	6,900	1.272	1.072	1.167	3,020
Hagador-Tin Mine	5.6	690	310	96	28	1.122	1.1013	1.197	640
Highgrove	4.8	540	260	105	40	1.125	1.025	1.188	520
Temescal	135.0	13,400	4,600	1,200	250	1.112	1.013	1.192	15,000
Lower Santa Ana near Yorba Linda	8.6	360	160	50	14	1.061	1.006	1.089	470
Santiago	63.0	11,600	5,200	1,600	470	1.112	1.013	1.207	7,600

1/ Number of times in 100 years peak discharges equalled or exceeded.

2/ Discharges for 40-year-old cover times factor converts discharge to other condition.

3/ Factor for present watershed cover condition with present fire protection level.

4/ Factor for watershed cover conditions expected with a complete program.

5/ Factor for first year after a large burn which equals one-fourth of the brush area in the watershed.

6/ One-fourth of brush area burned; larger burns are probable in small watersheds.

Sedimentation from Watersheds.- The estimation of sedimentation from watersheds during years for which no sediment catches were available was made from the relationship of actual reservoir catches to watershed and discharge variables. Regression analysis was used to study the relation of sedimentation to these variables. Since very few single storm catches of sediment have been recorded, the relationship between the yearly catches of sediment and the maximum yearly peak discharge and some watershed variables was tested in the analysis. The maximum yearly peak discharge was used as an index of the yearly sediment-producing potential. Other variables included in the analysis were cover density and area of main channel. Other variables probably influence sedimentation from watersheds, but the available data on sedimentation do not justify a more detailed analysis.

Regression Analysis Results.- Analyses were made of 23 annual measurements of sediment deposition in reservoirs from watersheds varying in area from 4.5 to 202 square miles. The equation which gave the best estimate was:

$$\text{Log } e_D = 1.041 + 0.8657 \log q - 1.2364 \log C + 0.3696 \log Ch$$ 3/

The standard error of estimate was $\pm$ 0.184 log units and the multiple correlation coefficient was .953. The standard errors of the regression coefficients were: for log q, $\pm$ 0.068; for log C, $\pm$ 0.956; and for log Ch, $\pm$ 0.250. Only the variable peak discharge was highly significant. The other two variables--cover and channel area--have been included here because each is significant when used separately in an equation with peak discharge to estimate sedimentation. Both are included to give the most reliable measure of individual effects and the best estimate of sedimentation.

Application of Equation.- Substituting in the equation the yearly peak discharges obtained from table 6 and figure 6 gives the frequency of yearly sedimentation amounts and a calculated average annual sedimentation which were corrected by the following method: In San Gabriel dam No. 1 for example, the total sediment catches in the 7-year period of 1937-38 to 1943-44 was 59.2 acre-feet per square mile for the 202-square-mile watershed. The sediment calculated from the discharges and watershed conditions during the same period was 51.5 acre-feet per square mile. The ratio of actual to calculated sedimentation was therefore 1.15. The calculated average annual sedimentation rate for 40-year-old cover obtained from application of the peak discharge frequency was multiplied by this factor, giving the estimated average annual sedimentation. Sedimentation for other cover conditions depends on (1) the change of sedimentation due to effect of cover in changing peak discharge and (2) the additional effect of changing cover on sedimentation. Working the cover changes first through the discharge equation, then through the sedimentation equation, will give the total effect on

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3/ See table 3 for definition of variables and units employed.

sedimentation. The same effect is obtained by substituting the cover change in an equation obtained by combining the discharge and sedimentation equation:

$$\text{Log } e = 2.1607 + 0.0712 \log A + 1.6193 \log P_{24} + 0.4101 \log aP + 0.3696 \log Ch - 1.9740 \log C$$

The sedimentation results by watersheds are summarized in table 8, which includes estimates of sedimentation under present watershed conditions and with average annual burn reduced to .2 of 1 percent as well as the effect of a large burn on sedimentation.

Table 8.- Expected sedimentation from subwatersheds under various watershed conditions

Watershed name	Area	Present rate of burn 2/	Average annual deposition: Present 3/	Average annual deposition: With reduced fires 4/	Sedimentation from .01 frequency flood 1/: Present watershed condition 3/	Sedimentation from .01 frequency flood 1/: Large burn 5/	Area of large burn 6/
	Sq.mi.	Percent	C.y.per sq.mi.	C.y.per sq.mi.	C.y.per sq.mi.	C.y.per sq.mi.	Acres
Big Dalton 7/	4.5	0.9	2,710	2,435	21,000	37,000	710
Big Dalton 8/	2.7	0.9	2,930	2,620	18,000	31,000	425
Fish	6.5	0.9	4,040	3,630	19,500	34,000	1,040
Little Dalton	3.3	0.9	3,150	2,830	19,600	34,500	530
Live Oak	2.3	0.9	2,650	2,270	12,500	20,400	320
Puddingstone 7/	2.6	0.9	7,070	6,500	53,500	94,500	390
Puddingstone 8/	12.3	0.9	2,420	2,090	11,000	13,500	970
Roberts	6.4	0.9	3,440	3,080	17,500	31,000	1,000
San Gabriel No.1	161.6	0.6	7,080	6,780	52,000	75,000	21,600
San Gabriel No.2	40.4	0.8	5,050	4,440	32,800	48,700	4,700
San Gabriel	202.0	0.6	6,675	6,310	48,200	69,600	26,300
San Dimas	15.9	0.9	3,400	3,080	25,800	45,400	2,500
San Jose	80.2	0.7	2,115	2,030	8,750	10,300	4,000
Thompson	3.9	0.9	2,980	2,555	12,500	21,700	610
Walnut	26.2	0.7	990	940	3,200	3,750	1,290

1/ Sedimentation expected from flood which frequency study shows will be equalled or exceeded once per hundred years.
2/ Expected average annual percentage of watershed burned under present fire protection level.
3/ Present condition of watershed and present burn percent.
4/ Sedimentation expected if the average annual burn were reduced to 0.2 percent.
5/ First year after large burn equal to 1/4 of the brush area in watershed.
6/ Area burned if 1/4 of brush area of watershed burned.
7/ Area above diversion.
8/ Area above dam.

Table 9.--Estimated sedimentation from subwatersheds under different watershed conditions

Drainage	Drainage area	Average annual sedimentation: Without program 2/	Average annual sedimentation: With program 3/	Sedimentation from .01 frequency flood 1/: Present watershed condition	Sedimentation from .01 frequency flood 1/: Large burn 4/	Area of large burn 5/
	Sq.mi.	C.y. per sq.mi.	C.y. per sq. mi.	C.y. per sq. mi.	C.y. per sq. mi.	Acres
San Antonio	26.7	6,280	1,210	81,000	110,000	2,430
Cucamonga	10.1	8,630	830	70,000	115,000	1,470
Day	4.8	9,770	7,610	60,000	91,000	600
Deer	3.7	7,340	5,510	91,000	135,000	420
East Etiwanda	3.1	4,590	3,870	40,000	69,000	500
San Sevaine	1.9	4,620	3,310	46,000	63,000	160
Lytle	47.9	6,560	690	77,000	101,000	3,520
Upper Cajon	40.9	6,580	2,580	51,000	88,000	6,290
Lone Pine	15.3	3,200	1,290	43,400	75,000	2,320
Devil	6.2	3,180	900	48,500	84,000	970
Strawberry	8.6	2,950	670	39,500	68,000	1,350
Sycamore near Devil	2.2	2,005	1,680	52,400	91,000	345
Sand	9.0	3,800	900	37,000	65,000	1,300
Little Sand	1.5	3,800	900	37,000	65,000	240
Waterman	4.6	4,840	1,070	47,000	81,000	720
City	19.7	3,230	370	23,000	40,000	3,150
Plunge	16.9	3,330	390	28,400	50,000	2,700
Mill	43.2	8,550	690	60,000	81,000	3,800
Santa Ana near Mentone	144.0	3,220	2,450	40,000	55,000	12,300
San Timoteo	118.0	1,570	465	10,500	14,300	10,100
Bautiste	54.5	2,790	2,220	22,400	38,000	8,300
West of Noble	1.9	1,900	780	58,000	58,000	0
Wilson--Potato	24.6	1,390	460	11,900	18,500	3,050
Edgar--Noble	22.8	2,180	720	32,000	48,000	2,700
Live Oak	23.4	1,390	460	12,000	16,600	2,230
Reche	11.6	1,600	450	8,800	13,000	1,350
Potrero	31.0	7,430	3,500	47,500	66,500	3,020
San Jacinto	140.0	4,150	2,430	51,000	71,600	13,000

Continued

Table 9.--Estimated sedimentation from subwatersheds under different watershed conditions - contd.

Drainage	Drainage area	Average annual sedimentation: Without program 2/	Average annual sedimentation: With program 3/	Sedimentation from .01 frequency flood 1/: Present watershed condition	Sedimentation from .01 frequency flood 1/: Large burn 4/	Area of large burn 5/
	Sq.mi.	C.y. per sq.mi.	C.y. per sq.mi.	C.y. per sq.mi.	C.y. per sq.mi.	Acres
Leach	2.6	1,500	885	16,500	24,400	300
Santa Ana near Prado 6/	1,465.0	600	405	10,700	14,800	140,000
Main--Eagle	4.3	1,500	1,295	15,200	22,500	490
Olive	5.1	1,570	520	17,200	24,000	480
Hagador--Tin Mine	5.6	1,500	1,295	14,500	21,400	640
Highgrove	4.8	1,320	440	19,000	27,600	520
Temescal	135.0	1,360	1,090	13,000	20,500	15,000
Lower Santa Ana near Yorba Linda	8.6	1,400	480	14,000	17,800	470
Santiago	63.0	3,230	2,600	26,600	40,400	7,600

1/ Sedimentation expected from flood which frequency study shows will be equalled or exceeded once per hundred years.

2/ Present condition of watersheds and present burn percent.

3/ Includes reduction due to a complete integrated program.

4/ First year after large burn equal to one-fourth of the brush area in watershed.

5/ Area burned if one-fourth of brush area of watershed burned.

6/ An estimated 15 percent of this sedimentation will pass through Prado Reservoir.

Conclusions.- The studies made to develop a hydrologic base for evaluation of the effects of changes in cover density indicated the following:

1) The observed discharges in this area, where discharge records are short and major fires cause wide variation in forest cover, are not a satisfactory base for determining discharge frequency. Adjustments of the observed discharges to a uniform forest cover condition and extension of the record on the basis of the long-term precipitation record provide such a base.

2) Sedimentation in individual reservoirs likewise is often not a good index of the long-time average to be expected. If the record of sedimentation was short, the floods during the period may not have been representative. Even if the record of sedimentation was fairly long, the fire history may not have been representative or the coincidence of fires and storms may have been exceptional. Basing estimates of average sedimentation on the long-time extended discharge record and adjusting to expected average cover conditions by use of the equations which were developed provided estimates which were independent of chance conditions.

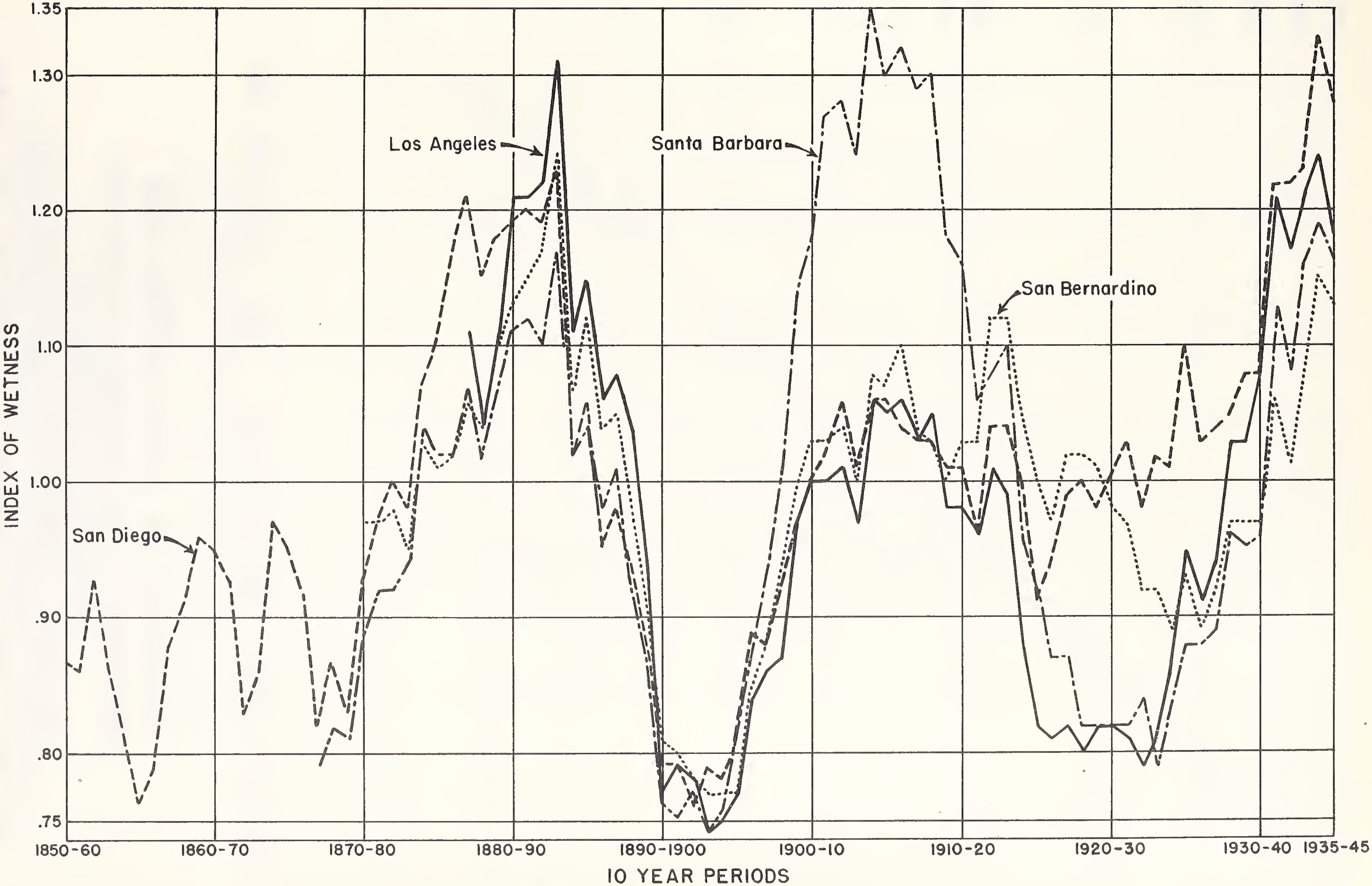
3) The expected discharges and sediment production in this basin are very high. Discharges as high as 666 second feet per square mile and sediment production of 60,000 cubic yards per square mile have been experienced from a single storm. A coincidence of storms of this size with poor cover have produced rates double these in nearby watersheds. The studies indicated that increased density of cover can bring about significant reductions in peak discharges and sedimentation of reservoirs. However, improved cover alone could not be expected to reduce sedimentation to desired levels. The channels of these watersheds are choked with debris. Land slips and talus slides reach into many channels. These are sources of material which require stabilization if the major share of the debris is to be kept out of the reservoirs.

It should be pointed out that the cover effects here measured, both for sedimentation and peak discharges, apply only to the present general level of watershed conditions. If during some future interval of time, the watershed receives improved protection for a long period, then soil building may occur and the maximum cover density may have an effect even greater than found here. If, on the other hand, misuse continues, the vegetation which occupies the area may be expected to become less and less dense. Under such conditions of decreased density, cover changes will be necessarily smaller, and a sustained higher level of peak discharges and sedimentation may be expected to result.

4) As to the adequacy of the methods employed, the study seems to comply fairly well with six criteria upon which a study in applied hydrology may be evaluated: In determining the basic relations (1) the data are representative in time, this was considered to be fairly well

met because the data used covered more than 20 years of discharges and 69 years of meteorological records; (2) the data used are representative in space, the watersheds included extended along a 100-mile front; (3) the effects measured are representative of actual effects, in this case they were the actual effects of meteorological and watershed variables on discharges from whole watersheds and sedimentation of actual reservoirs; (4) the effects measured are related to the desired end products, the damages produced by floods; (5) a suitable measuring device was employed, multiple regression analysis. And in the application of the results, (6) tests were made for the individual cases whenever possible and adjustments made on the basis of those tests.

PLATE TO ACCOMPANY HYDROLOGY APPENDIX — SAN GABRIEL AND SANTA ANA WATERSHED CALIF. — PREPARED JANUARY 8, 1948



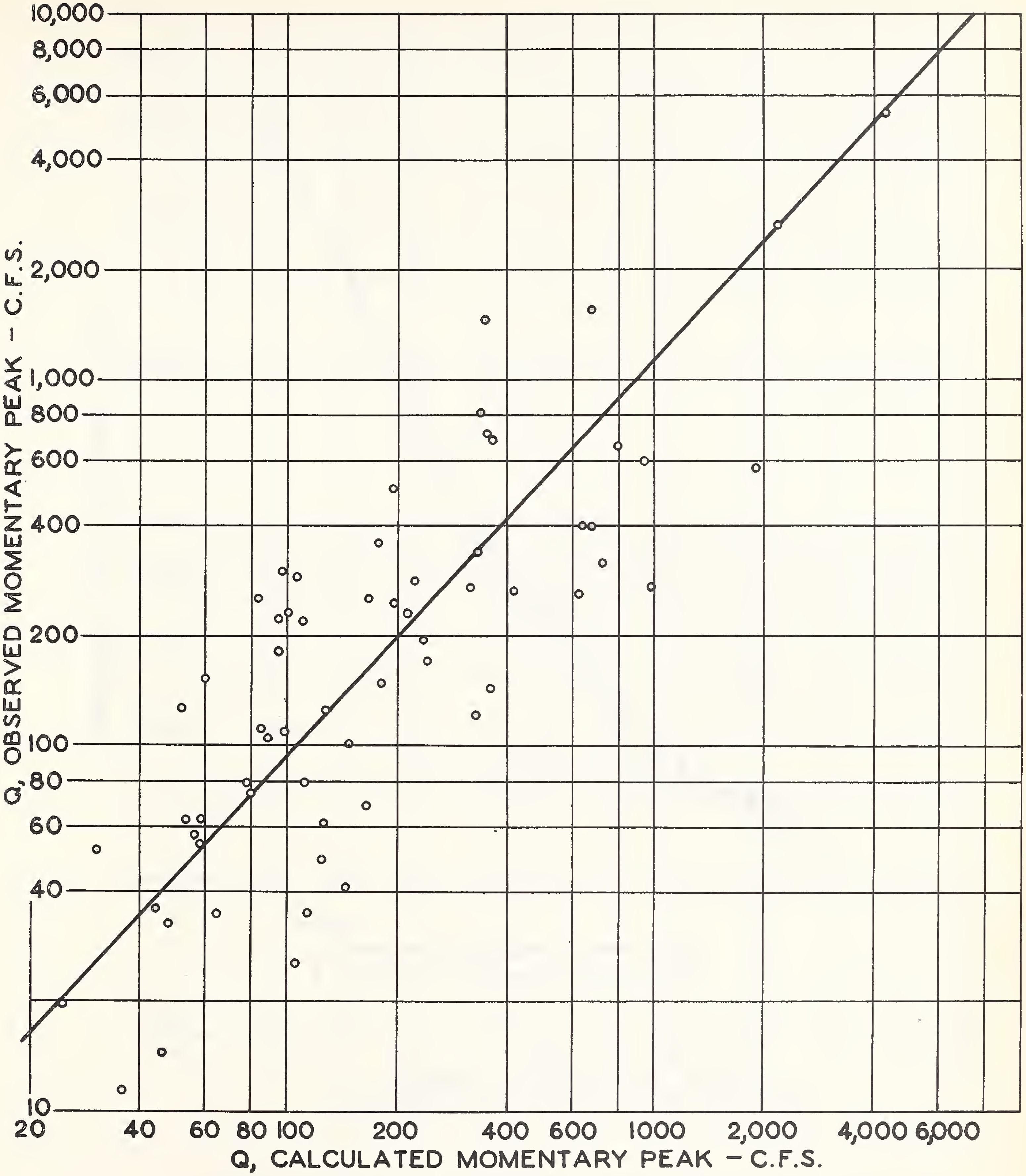
PROGRESSIVE 10 YEAR MEAN PRECIPITATION AT SELECTED STATIONS

AGRICULTURE - FOREST SERVICE - SAN FRANCISCO

Figure 1

Also San Gabriel River

ate to accompany Hydrology Appendix – Santa An iver Watershed – Calif. Prepared December 4, 1 7



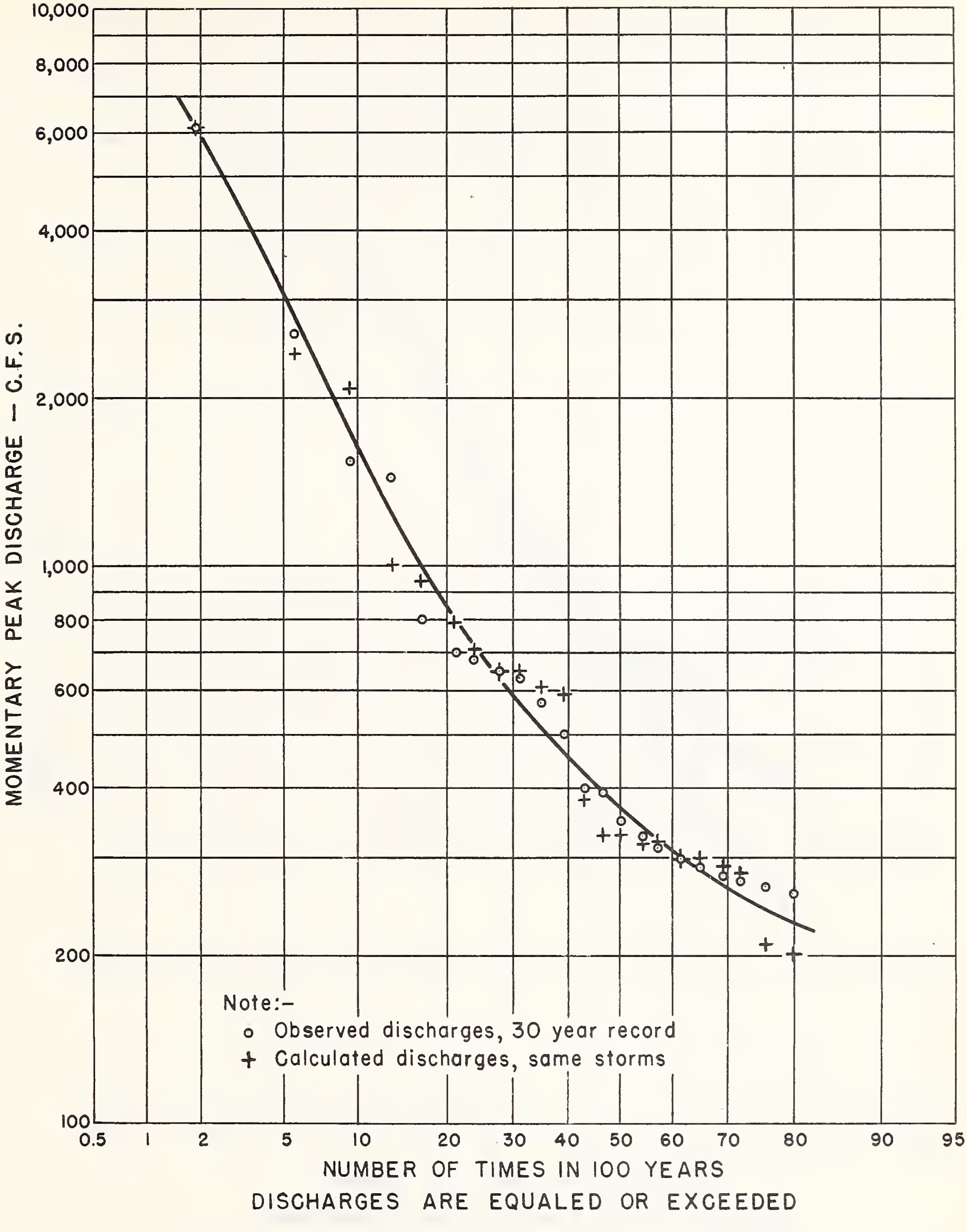
BIG SANTA ANITA WATERSHED

RELATION OF OBSERVED PEAK DISCHARGES
TO COMPUTED DISCHARGES
CALCULATED FROM THE GENERAL EQUATION:–

$$\text{Log } Q = 1.293 + 1.082 \log A + 1.870 \log P_{24} + 0.474 \log aP - 0.852 \log C$$

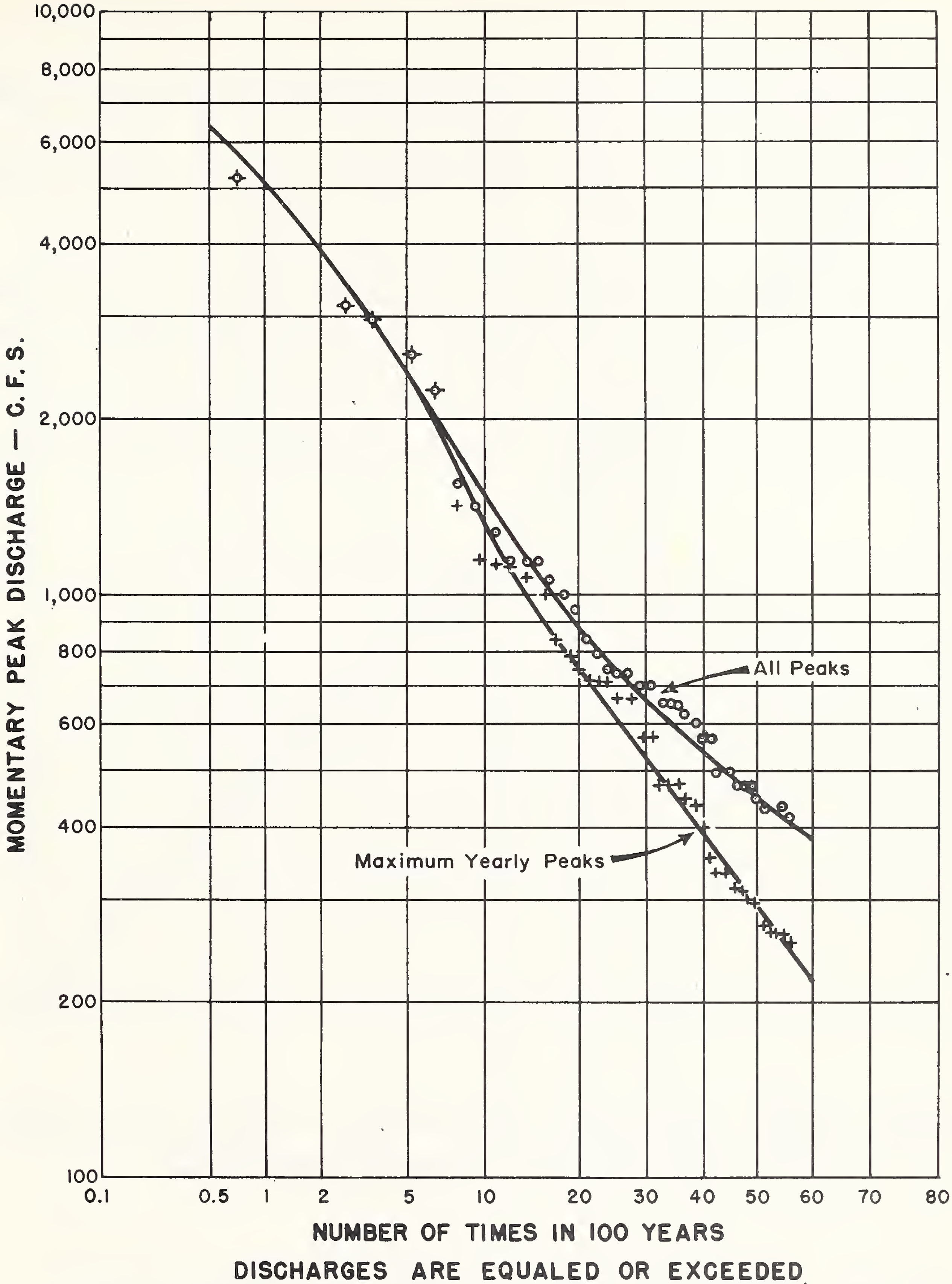
AGRICULTURE - FOREST SERVICE - SAN FRANCISCO

Figure 2



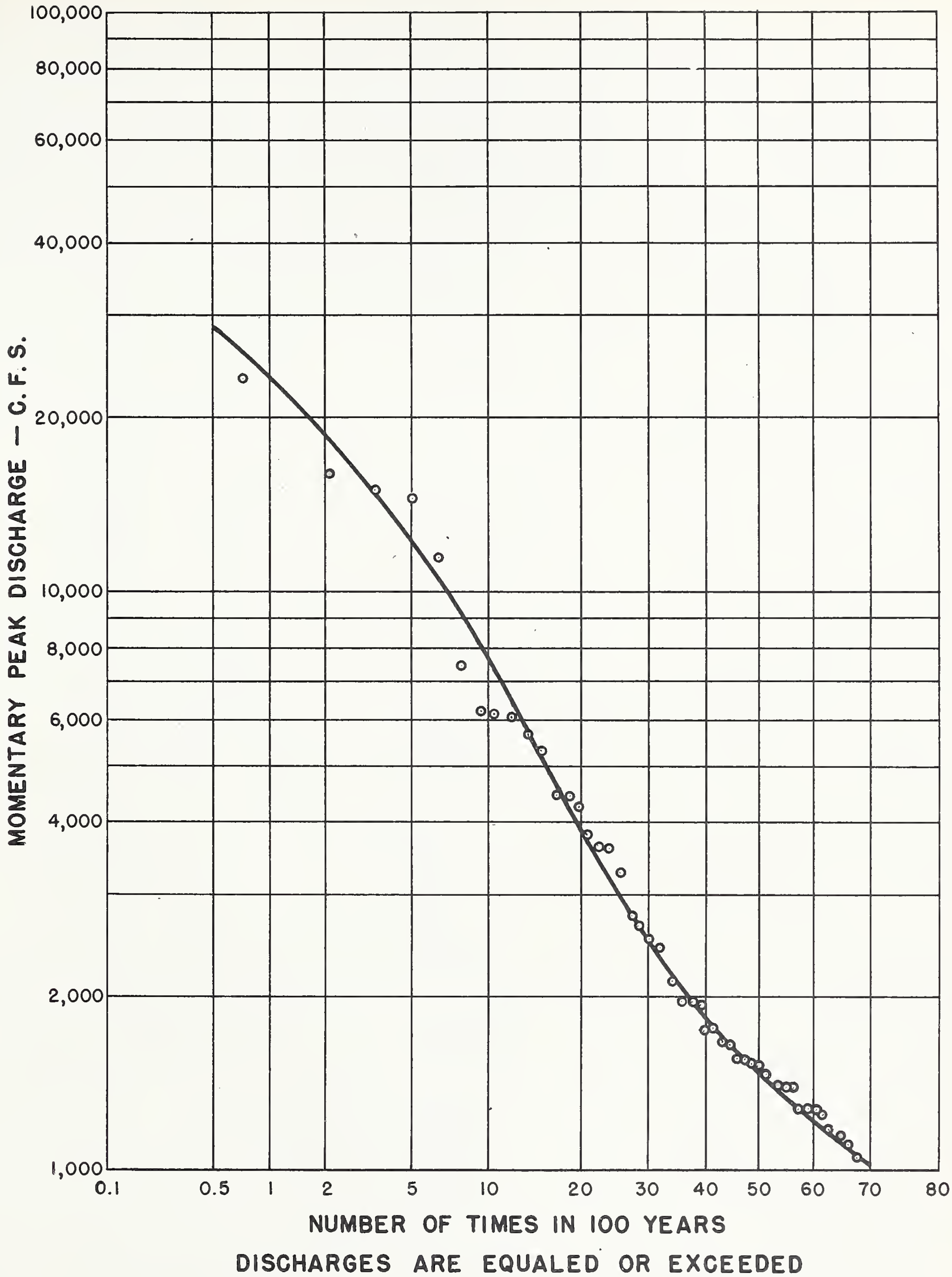
FREQUENCY CURVE - BIG SANTA ANITA

TEST OF RELATIONSHIP OF OBSERVED TO CALCULATED PEAK DISCHARGES BY COMPARISON OF FREQUENCY POINTS



FREQUENCY CURVE–BIG SANTA ANITA

MOMENTARY PEAK DISCHARGES
FOR 40-YEAR OLD VEGETATION



FREQUENCY CURVE — SAN GABRIEL NO. 2

MAXIMUM YEARLY MOMENTARY PEAK DISCHARGES

CORRECTED TO A BASIS OF 40-YEAR OLD VEGETATION

UNITED STATES DEPARTMENT OF AGRICULTURE

APPENDIX 3

FLOOD DAMAGES

San Gabriel and Santa Ana River Watersheds, California

To accompany report on survey, flood control,
San Gabriel and Santa Ana River Watersheds, California

APPENDIX 3

FLOOD DAMAGES

San Gabriel and Santa Ana River Watersheds, California

INTRODUCTION

Damages vary with the physical conditions in the watershed. In the mountains flood flows cut through or shear away narrow flats along the rivers destroying recreational and utility improvements such as cabins, camps, roads, and trails. From steep mountain sides mudflows pour down between naturally-built dikes upon recreational developments, devastating buildings and covering the ground deep with debris. Often ancient river deposits towering high above the present channel are undercut and mud, rocks, trees, and buildings tumble into the raging streams.

In many valley areas stream channels do not form because of the large volume of debris carried down from the mountains. Here floodwaters spread extensively and do great damage to orchards, vineyards, roads, and railroads. In other places sedimentation has so raised the river and creek bottoms that floodwaters overflow the shallow banks and inundate the surrounding countryside. Then again the river waters break out of their present channels to return to an ancient channel to flood and destroy everything in their path. At the mouth of many canyons water-spreading grounds are destroyed or badly damaged and have to be rebuilt after every large flow. Improved channel ways on many streams now confine the flows and dams regulate their magnitude. At present farms, industrial plants, roads, and towns along these streams are beyond the reach of all but the largest floods. The erosional debris that in the past built up the valleys is now lodging in these flood-control structures. Their life will be short unless the debris is continually removed.

Debris is now removed by excavation from debris basins and by sluicing from some reservoirs. In the Santa Fe Reservoir debris space is provided by sale of the gravel deposits in this reservoir.

Extensive areas along the mountain stream courses, in the interior valley below the foothills, and below valley hills still remain unprotected against flood and debris flows.

PAST FLOOD DAMAGES

Records of flood damages for early years are sketchy and confined almost entirely to the more densely populated San Gabriel and Los Angeles River drainages. These reports came from mission records, diaries, letters,

newspaper reports, and court hearings. The earliest mention 1/ of floods is in 1770 when the San Gabriel Mission and the bottom land around the Mission were damaged. In 1772 the Mission was again damaged and then moved six miles back from the river to its present location.

In 1815 the Los Angeles River changed its course from the east to the west side of the part of the valley which is now Los Angeles City. In 1822 the Los Angeles River covered the whole plain. In 1825 the Los Angeles River cut a direct course to the sea abandoning its former drainage outlet through Ballona Creek into Santa Monica Bay.

In 1862 was the greatest of all known floods. The Santa Ana River was a raging torrent and the colonies along the river were completely inundated. Vineyards, orchards, and grain fields were transformed into a barren waste. At Anaheim the river ran 4 feet deep and spread in an unbroken sheet to the Coyote Hills, 3 miles beyond. Lytle Creek roared through San Bernardino and cut through into Warm Creek. Enough driftwood was brought down by the Santa Ana to provide firewood and saw timber for years. The whole valley from Los Angeles to the ocean was one great lake. The Los Angeles River split, part of the water going to the ocean through the channel cut in 1825 and the rest through Ballona Creek. The San Gabriel River started a new channel east of El Monte.

In 1867 the San Gabriel River formed a new channel below El Monte and washed away several thousand acres of land. Along the Santa Ana there was much damage but it was not as severe as in 1862.

In 1884 a moderately intense storm fell on watersheds almost completely denuded by fires some years earlier. This resulted in a severe flood, The Santa Ana River cut a new channel to the sea, beginning at Santiago Creek and discharging into the ocean 3 miles southeast of its former outlet. Much fertile land was lost. All bridges, save one, across the Los Angeles River were washed away, many houses were lost and several people drowned. The floodwaters of the Los Angeles River poured again down their old path through Ballona Creek and the country back of Venice became a great lake. The San Fernando Valley also was flooded from end to end.

In 1889 the new and old San Gabriel Rivers and the Los Angeles formed one body of water near Downey and swept everything with them. No major flood occurred until 1916 when damage valued at 1½ million dollars was done in the Santa Ana basin. In this flood 6 lives were lost.

Minor floods were noted in 1918, 1921, 1926, 1927, 1931, 1932, 1934, 1936, and 1937. Of all these events, the New Year's flood of 1934 in La Canada above Los Angeles was the most disastrous. It drew attention to the devastating effect of a moderately intense storm falling upon a freshly fire-denuded watershed. Over 600,000 cubic yards of debris were

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1/ These and following reports are for the most part from "Floods of March 1938 in Southern California," Geol. Sur. Water Supply Paper 844.

moved from 7.5 square miles of mountain slopes onto the valley floor. Buildings, villages, vineyards, citrus groves, and highways were devastated. Property damage exceeded $5,000,000 and 40 people lost their lives. 2/

The 1938 floods were again widespread and among the "great." On the San Gabriel it was the greatest of record. Floodwaters and debris poured from the steep mountain canyons and spread over extensive tracts of land in the plain and below the foothills. This occurred even with the large storage capacities of the San Gabriel dams and Morris Dam on the San Gabriel River and flood-control dams in most of the larger tributaries. Much of the 1938 floodwater of the San Gabriel River flowed through the Rio Hondo into the Los Angeles River.

After the 1938 flood a detailed damage survey was undertaken by the Corps of Engineers, Department of the Army. The total direct damage along the major streams in the San Gabriel-Coyote Creek flood plain amounted to $5,665,800.

These damages are summarized in table 1 and reflect the economic development and values at that time.

The exceedingly high damage in the Coyote Creek basin was caused largely by the Santa Ana River, which overflowed northwest of Anaheim, following an old course to converge with the floodwaters of Carbon, Fullerton, La Brea, and Coyote Creeks.

2/ "Flood in La Canada Valley, California, January 1, 1934," by Harold C. Troxell and John A. Peterson, Water Supply Paper 796-C.

Table 1.- Damages from storm of February 27 to March 3, 1938

Character of property	Damage: San Gabriel River basin	Damage: Coyote Creek basin
	Dollars	Dollars
Residential	183,200	898,600
Business	137,100	518,900
Industrial	39,200	29,500
Agriculture	242,600	1,445,200
Highways and roads	340,500	171,700
Highway bridges	26,100	--
Railways and bridges	47,500	93,400
Electric railways	69,000	13,000
Water systems	198,500	14,000
Sewer systems	6,600	95,000
Gas systems	6,000	15,100
Electric systems	27,200	1,200
Telephone systems	4,100	--
Telegraph systems	1,800	--
Channel improvements	461,900	53,000
Miscellaneous	513,600	12,300
Total	2,304,900	3,360,900

For the Santa Ana River the Corps of Engineer' 1938 survey showed damages amounting to $22,000,000. After the 1943 flood similar surveys were made by that agency for some drainages where great damage was done to military establishments and war industries.

Estimated Future Flood Damage in the San Gabriel Watershed.- Flood data in table 1 include only a small portion of damages from local runoff, small tributaries, and the headwaters in the San Gabriel watershed. A complete survey of these areas was made in 1940 to obtain the losses incurred in the 1938 flood. These data were adjusted to represent present conditions and values and they form the basis for damage estimates by types of properties as shown in the group of tables 4-a to 4-k. The accompanying discharges are in each case those for the major creek in the area or adjacent to it.

Total damages from tributaries, drainages above existing or authorized flood-control works, and local runoff for floods of the 1938 magnitude are summarized in table 2.

Tables 4-a to 4-k also show three smaller discharges and the correspondingly estimated damage, which is based on an estimated probable

overflow area for a given size flood and the value of improvements in the area.

Table 2.- Summary of tributary damages for broad areas from the 1938 flood (1947 values)

Area	Damage Direct	Damage Indirect	Damage Total
	Dollars	Dollars	Dollars
Valley	1,189,900	107,100	1,297,000
High mountains	1,003,600	11,300	1,014,900
Frontal mountains	487,300	2,600	489,900
Total	2,680,800	121,000	2,801,800

Damages from these four flood sizes form the basis for the damage-discharge relationship for each area. Flood frequency relationships for each area are presented in the appendix on hydrology. From these two sets of data the average annual damage is calculated. The average annual damage is further increased by the amount of damage expected from future development without flood control. The estimated percent increase of damage expected from future development, based primarily upon estimated population growth, is footnoted in each of the tables in the series 4-a to 4-k. The general trend of population growth in Yeatman's 3/ studies has been accepted after adjustment for the unexpected wartime growth. Population growth is assumed to level off by the year 2000. Estimates of growth by drainage areas are based on past trends in development in these areas. Areas near existing industrial and population centers are expected to draw most of the population in the future. Consequently increased damage due to future development generally will be greater in the western portion of the watershed, particularly the central southwest portion.

Total average annual damages from tributaries, including estimated increases for future development, are about $386,700 under present watershed conditions and the current level of fire protection. This assumes that all authorized and existing downstream flood-control works are installed and functioning. Table 3 lists these damages by subwatershed.

3/ Yeatman, Jones. A study of population trends in Los Angeles and the Nation. Los Angeles 1933. And supplement: California population estimates to 1960, Los Angeles, 1935.

Table 3.- Average annual flood damage in local areas, tributaries, and headwaters, by drainage areas (1947 values)

Subwatershed	Average annual damage, present protection
	Dollars
San Gabriel No. 1	42,200
San Gabriel No. 2	11,030
Morris Dam	15,680
Fish and Roberts Canyons	19,000
Little Dalton	
Mountain area	1,900
Valley area	4,890
Big Dalton	
Mountain area	8,920
Valley area	5,300
San Dimas-Walnut Creek	
Mountain area	14,550
Valley area	9,320
Live Oak-Marshall Creek	2,160
Thompson Creek above dam	4,020
San Jose Creek	20,580
San Jose Valley, tributaries and local runoff	49,530
Puente Hills and South Whittier Heights	104,450
La Brea-Rodeo Creek	9,550
Fullerton Creek	2,130
Carbon Creek	3,400
Carbon Hills	5,300
Artesia-Norwalk area	52,840
Total	386,750

Table 4-a.- Damages in San Gabriel Canyon area for various discharges, 1947 values 1/

Item	Damage: Direct	Damage: Indirect	Damage: Total
	Dollars	Dollars	Dollars
Above San Gabriel Dam No. 1			
Cabins	85,750	8,600	94,350
Roads and highways	275,100	13,800	288,900
Forest Service roads & trails	128,650	0	128,650
Public property	193,100	0	193,100
Total, 84,100 c.f.s.	682,600	22,400	705,000
63,000 c.f.s.			411,600
42,000 c.f.s.			244,400
21,000 c.f.s.			103,670
Above San Gabriel Dam No. 2			
Cabins	17,150	1,700	18,850
Highways	128,600	0	128,600
Forest Service roads & trails	22,800	0	22,800
Public property	8,750	0	8,750
Flood-control structures	17,100	0	17,100
Total 29,000 c.f.s.	194,400	1,700	196,100
17,000 c.f.s.			99,500
11,000 c.f.s.			44,600
6,000 c.f.s.			12,860
Above Morris Dam			
Roads and highways	100,000	5,000	105,000
Forest Service roads	7,400	0	7,400
Water system	7,600	1,000	8,600
Public property	11,700	0	11,700
Total, 1,740 c.f.s.	126,700	6,000	132,700
1,300 c.f.s.			77,200
900 c.f.s.			52,300
400 c.f.s.			17,200

1/ No increase in future development expected.

Table 4-b.- Damages in Fish and Roberts Canyons for various discharges, 1947 values 1/

Item	Damage Direct	Damage Indirect	Damage Total
	Dollars	Dollars	Dollars
Agriculture	24,400	2,400	26,800
Residences	18,500	1,900	20,400
Roads	2,900	0	2,900
Water systems	55,740	0	55,740
Forest Service roads	8,580	0	8,580
Public property	12,860	0	12,860
Total, 1,740 c.f.s.	122,980	4,300	127,280
1,300 c.f.s.			66,900
900 c.f.s.			42,200
400 c.f.s.			17,200

1/ Thirty-two percent increase in damage due to future development not included.

Table 4-c.- Damages in Big Dalton drainage for various discharges, 1947 values

Item	Damage Direct	Damage Indirect	Damage Total
	Dollars	Dollars	Dollars
Valley area 1/			
Agriculture	11,900	1,200	13,100
Roads	4,670	0	4,670
Total, 810 c.f.s.	16,570	1,200	17,770
610 c.f.s.			9,400
400 c.f.s.			5,660
200 c.f.s.			2,660
Below dam 2/			
Roads	36,360	440	36,800
Flood control structure	3,400	0	3,400
Total, 810 c.f.s.	39,760	440	40,200
610 c.f.s.			24,100
400 c.f.s.			16,100
200 c.f.s.			6,000
Above dam 2/			
Public property	120,700		120,700
Total, 1,320 c.f.s.			120,700
1,000 c.f.s.			73,700
700 c.f.s.			43,900
300 c.f.s.			16,300

1/ Discharge frequencies same as for San Jose Creek. Thirty-six percent increase in damage due to future development not included.

2/ Increase due to future development, 0 percent.

Table 4-d.- Damages in Little Dalton drainage for various discharges, 1947 values

Item	Damage: Direct	Damage: Indirect	Damage: Total
	Dollars	Dollars	Dollars
Valley area 1/			
Agriculture	45,380	4,540	49,920
Business	1,770	0	1,770
Roads and bridges	14,920	1,500	16,420
Total, 915 c.f.s.	62,070	6,040	68,110
700 c.f.s.			24,000
200 c.f.s.			7,700
Mountain area 2/			
Roads	27,500	1,400	28,900
Water systems	900	0	900
Public property	2,600	0	2,600
Total, 915 c.f.s.	31,000	1,400	32,400
700 c.f.s.			18,900
500 c.f.s.			13,700
200 c.f.s.			6,860

1/ Thirty-two percent increase in damages due to future development not included.

2/ Increase due to future development, 0 percent.

Table 4-e.- Damages in San Dimas-Walnut Creek drainage for various discharges, 1947 values

Item	Damage: Direct	Damage: Indirect	Damage: Total
	Dollars	Dollars	Dollars
Valley 1/			
Agriculture	22,560	2,260	24,820
Roads	7,800	780	8,580
Public property	1,030	0	1,030
Total, 4,920 c.f.s.	31,390	3,040	34,430
3,700 c.f.s.			18,000
2,500 c.f.s.			11,150
1,250 c.f.s.			5,660
Mountain 2/			
Cabins	18,870	1,900	20,770
Public property	217,100	0	217,100
Roads	27,220	0	27,220
Water systems	3,430	0	3,430
Flood-control structures	29,200	0	29,200
Total, 4,920 c.f.s.	295,820	1,900	297,720
3,700 c.f.s.			181,790
2,500 c.f.s.			109,760
1,250 c.f.s.			46,300

1/ Thirty-three percent increase in damages due to future development not included.

2/ Increase due to future development, 0 percent.

Table 4-f.- Damages in Live Oak and Marshall Canyons for various discharges, 1947 values 1/

Item	Damage: Direct	Damage: Indirect	Damage: Total
	Dollars	Dollars	Dollars
Agriculture	11,400	1,200	12,600
Highways	5,150	500	5,650
Roads	2,100	0	2,100
Total, 5,310 c.f.s.	18,650	1,700	20,350
4,000 c.f.s.			10,800
2,600 c.f.s.			6,000
1,300 c.f.s.			2,600

1/ Twenty-seven percent increase in damage due to future development not included.

Table 4-g.- Damages in Thompson Creek drainage above dam for various discharges, 1947 values 1/

Item	Damage: Direct	Damage: Indirect	Damage: Total
	Dollars	Dollars	Dollars
Cabins	4,300	430	4,730
Flood-control structures	4,300	0	4,300
Roads	31,600	0	31,600
Total, 580 c.f.s.	40,200	430	40,630
400 c.f.s.			21,800
300 c.f.s.			14,900
150 c.f.s.			6,500

1/ No increase anticipated for future development.

Table 4-h.- Damages in LaBrea-Rodeo, Carbon Canyon, and Fullerton areas for various discharges, 1947 values

Item	Damage: Direct	Damage: Indirect	Damage: Total
	Dollars	Dollars	Dollars
La Brea-Rodeo 1/			
Agriculture	7,890	790	8,680
Business and industry	8,750	880	9,630
Roads	26,400	1,320	27,720
Total, 1,970 c.f.s.	43,040	2,990	46,030
1,500 c.f.s.			14,150
1,000 c.f.s.			9,430
500 c.f.s.			4,120
Carbon Canyon 2/			
Business	2,740	300	3,040
Roads	13,900	860	14,760
Total, 1,970 c.f.s.	16,640	1,160	17,800
1,500 c.f.s.			10,700
1,000 c.f.s.			7,290
500 c.f.s.			3,000
Fullerton 3/			
Agriculture	6,200	600	6,800
Roads	2,400	200	2,600
Total, 1,970 c.f.s.	8,600	800	9,400
1,500 c.f.s.			6,000
1,000 c.f.s.			3,800
500 c.f.s.			1,540

1/ Sixteen percent increase in damages due to future development not included.

2/ Ten percent increase in damages due to future development not included.

3/ Twenty-four percent increase in damages due to future development not included.

Table 4-i.- Damage in Puente Hills and South Whittier Heights area for various discharges, 1947 values 1/

Item	Damage Direct	Damage Indirect	Damage Total
	Dollars	Dollars	Dollars
Agriculture	246,270	24,600	270,870
Residence	7,900	790	8,690
Roads	46,200	2,300	48,500
Railroads	41,200	8,200	49,400
Sewer and water	2,600	0	2,600
Total, 9,400 c.f.s.	344,170	35,890	380,060
7,000 c.f.s.			198,900
4,700 c.f.s.			120,000
2,400 c.f.s.			58,700

1/ Thirty-six percent increase in damage due to future development not included.

Table 4-j.- Damages in San Jose Valley for various discharges, 1947 values 1/

Item	Damage Direct	Damage Indirect	Damage Total
	Dollars	Dollars	Dollars
San Jose Creek 1/			
Agriculture	94,600	9,500	104,100
Residence	5,150	500	5,650
Roads	18,830	3,460	22,290
Utilities	6,860	0	6,860
Channel structures	14,580	0	14,580
Total, 9,400 c.f.s.	140,020	13,460	153,480
7,000 c.f.s.			58,310
4,700 c.f.s.			15,440
2,400 c.f.s.			3,100
San Jose tributaries 1/			
Agriculture	172,580	17,360	189,940
Residence	380	0	380
Roads	12,100	0	12,100
Total, 9,400 c.f.s.	185,060	17,360	202,420
7,000 c.f.s.			107,200
4,700 c.f.s.			64,760
2,400 c.f.s.			30,870

1/ Exclusive of Thompson Creek. Twenty-five percent increase in damage due to future development not included.

Table 4-k.- Damages in Artesia, Norwalk, and Carbon Hill areas for various discharges, 1947 values

Item	Damage: Direct	Damage: Indirect	Damage: Total
	Dollars	Dollars	Dollars
Artesia-Norwalk 1/			
Agriculture	113,530	11,350	124,880
Residence	340	0	340
Industry	1,060	0	1,060
Roads	28,040	5,600	33,640
Total, 9,400 c.f.s.	142,970	16,950	159,920
7,000 c.f.s.			94,330
4,700 c.f.s.			63,970
2,400 c.f.s.			25,730
Carbon Hills 2/			
Agriculture	17,580	1,720	19,300
Total, 1,970 c.f.s.			19,300
1,500 c.f.s.			10,250
1,000 c.f.s.			6,200
500 c.f.s.			2,900

1/ Forty-eight percent increase in damages due to future development not included.

2/ Thirty-six percent increase in damages due to future development not included.

FUTURE AVERAGE ANNUAL FLOOD DAMAGE, SANTA ANA WATERSHED

Damage estimates were made for areas that are now unprotected or only partially protected and for which no major flood control structures are planned by other agencies. The estimates were based on experienced damages wherever possible. Detailed damage data for the whole area are available for the 1938 flood. The 1938 survey made by the Corps of Engineers for the major streams was supplemented in 1941 by the U. S. Department of Agriculture survey for the mountains and overflow areas of smaller streams. Damage surveys for the 1943 flood were also made by the Corps of Engineers for certain areas. Scattered records are available for the 1936 and 1937 flows. Extensive use has been made of these data for estimating future damages. The area overflowed by the 1938 flood was traced from aerial photographs made shortly after the flood. These photographs were also used to determine overflow areas for other size floods and to determine the different courses any flow might take. For each flood size the probability was considered that a flow would follow the most probable course through its present channel and alternative courses. This reflects the likelihood that during a given flood the present channel would be blocked by debris and the flow diverted successively through one or more alternative courses. It also takes into consideration the possibility that succeeding flows in a single year would follow different courses, hence damage from each flow would be independent of damage caused by the preceding flow. Damage estimates by overflow areas and for several discharges are shown in tables 6a to 6y. These estimates include direct damages, that is, destruction caused by the direct impact of floodwaters on property, and indirect damages, such as construction of temporary bridges or roads, diversion of traffic, temporary housing until damaged houses are repaired and all such damages flowing from direct losses. They include sediment damages to land and all other properties, but do not include damages caused by sedimentation of reservoirs, basins, and channel ways. These are discussed separately in a later part of this appendix. The estimates given in those tables also do not include damages which will be eliminated by measures planned by agencies other than the U. S. Department of Agriculture. Tables 6a to 6y give a description of the damages in the respective area and an estimate of the percent by which damages will increase because of future development. These percent increases are based upon a recent study by the Corps of Engineers of future development in the Santa Ana drainage.

The damages for the several discharges given in these tables, when plotted, give the basis for the damage-discharge curve for each area. Damage for any discharge magnitude can be read from this curve. Similarly, a curve for flood frequencies with given watershed conditions can be plotted from the data in table 7, Appendix 2. A combination of these two curves gives the damage-frequency curve. The area under this curve equals the total damage expected during a 100-year period and the average annual damage is the hundredth part of the area under the curve.

The average annual flood damages by areas in the sequence followed in tables 6a to 6y are shown in table 5.

Table 5.--Average annual flood damages, 1946 values, Santa Ana watershed

Damage area	Average annual flood damages	Damage area	Average annual flood damages
	Dollars		Dollars
San Antonio Canyon	24,300	San Jacinto (Potrero)	19,300
Cucamonga	21,000	Lamb Creek	300
Deer and Day	28.900	Parris Valley (western channel)	2,200
Etiwanda	2,800	Reche Canyon	1,000
San Sevaine	7,500	Highgrove area	7,000
Frankish Front	17,600	Arlington area	41,600
Lytle Creek	49,200	Hagador and Tin Mine	4,100
Cajon	95,300	Eagle and Main	2,900
Devil and Cable Canyons	5,700	Halladay	2,100
Waterman and Strawberry	10,500	Yorba Linda School	1,600
Sand, Little Sand, Borea	10,500	Richfield	4,400
City Creek	6,700	Villa Park	10,700
Santa Ana above Mentone	13,400	Coastal Plain:	
Mill Creek	29,900	Anaheim area	44,800
Sycamore Canyon	4,100	Garden Grove	30,600
Jurupa Hills	500	Tustin area	17,800
San Timoteo	28,300	Costa Mesa	1,100
Edgar, Noble, Marshall	18,300	Wildwood (Livcoak)	3,400
Olive Creek	16,700	Wilson and Potato	4,900
		Total	$591,000

The average annual flood damage under present watershed conditions and expected future economic development for the areas which are now either unprotected or only partially protected or for which no protection is planned at present by agencies other than the U. S. Department of Agriculture is $591,000 at 1946 prices.

FLOOD DAMAGES BY DRAINAGE

The damages given below reflect the present state of development. Indications of the increase in damages that may be expected with future development are also shown. All damage data represent 1946 values.

San Antonio Canyon.--Congress authorized the Corps of Engineers to construct a combination debris and flood-regulation basin at the mouth of this canyon. The structure when built will eliminate all damages in the valley below from this source. Damages to cabins, recreational facilities, power and water development, roads, and bridges above the flood control structure will continue.

Prior to 1938 cabins crowded all but the center of the creeks. Consequently damage from the March 1938 flood was enormous. About half of the 600 cabins were destroyed and 140 damaged. Power, water, telephone facilities, and roads suffered great destruction. Some of the power facilities were abandoned and many of the cabins were not rebuilt.

It is estimated that the present development will continue about the same in the future. Nevertheless shifts in local development must be expected along with future floods. Many of the habitable areas in the canyon will be destroyed by future floods. Debris carried by these floods will form new sites for development to replace in part those destroyed.

On this basis, damage estimates have been made for flood discharges of 14,000 c.f.s., 7,000 c.f.s., and 2,500 c.f.s. at the canyon mouth. In making the estimates for direct flood damages the possibility of alternate routes and their probability has been taken into account.

Table 6a -Summary of damage estimates by flood sizes, San Antonio Canyon (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Cabins, restors, etc.	287,100	57,500	344,600
Power facilities and telephones	137,800	13,700	151,500
Roads and bridges	135,500	20,300	155,800
Water facilities	8,700	1,300	10,000
Miscellaneous public property	4,300	0	4,300
Total for 14,000 c.f.s. flood	573,400	92,800	666,200
Cabins and resorts	95,400	19,000	114,400
Power facilities and telephones	61,100	6,100	67,200
Roads and bridges	96,900	14,600	111,500
Water facilities	2,400	400	2,800
Miscellaneous public property	2,800	0	2,800
Total for 7,000 c.f.s. flood	258,600	40,100	298,700
Cabins, resorts, etc.	14,300	1,400	15,700
Power facilities and telephones	14,300	1,400	15,700
Roads and bridges	29,200	4,400	33,600
Water facilities	1,300	100	1,400
Miscellaneous public property	700	0	700
Total for 2,500 c.f.s. flood	59,800	7,300	67,100

Cucamonga Area.--A series of barriers at the mouth of the canyon and the spreading ground below greatly moderated damage in the valley from recent floods. Debris was retained and the waters spread over a fairly wide cone. Without these structures the east channel is likely to be blocked as it has been in the past, and the full force of the flow would then concentrate in the west channel to overflow citrus orchards and the towns of Upland and Ontario.

Protection against floods, therefore, depends not only upon a restrictive channel but also on the maintenance of the debris barriers to assure flows free of heavy sediment. The county is now completing work on a channel that will carry medium-sized flood flows.

A damage appraisal based on the floods of 1938, 1943, and 1936 has been made for the three flood sizes. Table b shows the losses to be expected with present development at 1946 values, assuming operation of the barriers and spreading works but disregarding channel improvements.

In addition to the damages shown in table 6, damage to future development has to be added. This amounts to an increase of 19 percent, based upon the recent Corps of Engineers' study.

Completion of the county channel will eliminate all damages from medium-sized floods.

Table 6b -Summary of damage estimates by flood sizes, Cucamonaga Canyon (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Agriculture	542,700	108,500	651,200
Business, residential, Federal	2,300	800	3,100
Highways and bridges	114,300	22,900	137,200
Railroads and bridges	57,200	11,400	68,600
Utilities	100,000	40,000	140,000
Channel improvements	178,900	0	178,900
Total for 10,300 c.f.s. flood	995,400	183,600	1,179,000
Agriculture	108,300	21,700	130,000
Business, residential, Federal	2,800	900	3,700
Highways and bridges	32,700	4,300	37,000
Railroads and bridges	200	--	200
Utilities	3,900	1,100	5,000
Channel improvements	38,700	--	38,700
Total for 1,400 c.f.s. flood	186,600	28,000	214,600
Agriculture	7,400	1,500	8,900
Highways and bridges	8,100	700	8,800
Total for 475 c.f.s. flood	15,500	2,200	17,700

Deer, Day, Etiwanda, San Sevaine Area.--The mountainous watersheds of these streams are small; consequently, the flood flows are not sufficient to develop definite channels as in San Antonio and Cucamonga Creeks. Each of these streams has numerous interrupted channels meandering across the valley land. The amount of debris carried is high; therefore, the flow often shifts from channel to channel as each is blocked by debris deposits. Concentration of water causes extremely high damages even with medium-sized floods.

The flood plain of Deer and Day Creeks is not as highly developed as that of the adjacent areas. It is almost an exclusively agricultural

area, predominantly vineyards. The only major development is an Army Army Quartermaster Depot. The county is now improving the Day Creek channel to take care of small to medium-sized floods. Drifting sands are a threat to channel improvement below the upper cone. The Etiwanda and San Sevaine overflow areas are more highly developed than those of Deer and Day. Channel improvements have been made near the Fontana steel mill located in the overflow area. Threat of direct flood damage to the mill is not great. Highways and railroads are vulnerable and interruption of traffic by floods will affect greatly the prosperity of this area.

Numerous small canyons between San Antonio and Deer Canyons discharge onto some of the basin's finest citrus groves. Their flows, although partly channelized, do excessive damage to both farmland and highways. Their waters mingle with those of Deer and Day Canyons and also of Cucamonga Creek.

Damage estimates have been made for various flood sizes based upon damage experienced in 1938, 1943, and 1936 or 1937 and on present developments and values. Since the floodwaters of these streams intermingle, the damage for each group of streams separately is approximate.

Table 6c-Summary of damages by flood sizes, Deer and Day overflow area (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Agriculture	463,300	92,700	556,000
Business, residential, Federal	11,300	3,400	14,700
Highways and bridges	36,600	7,400	44,000
Railroads and bridges	68,900	30,400	99,300
Utilities	10,500	4,200	14,700
Channel improvements	88,000	0	88,000
Total for 8,360 c.f.s. flood	678,600	138,100	816,700
Agriculture	13,100	3,000	16,100
Business, residential, Federal	300	100	400
Highways and bridges	13,500	1,400	14,900
Railroads and bridges	900	100	1,000
Utilities	300	100	400
Channel improvements	15,700	0	15,700
Total for 2,160 c.f.s. flood	43,800	4,700	48,500
Agriculture	4,000	300	4,300
Highways and bridges	1,300	400	1,700
Railroads and bridges	400	0	400
Total for 320 c.f.s. flood	5,700	700	6,400

a. Deer and Day Canyons.-- Future development will increase damages by about 17 percent. Damage from a flood of 2,160 c.f.s. as given in table c does not consider undue concentration of flood waters. Allowance is made for this by assuming three different paths in two floods. All medium-sized floods would be similarly affected.

b. Etiwanda Area.--A 1,225 c.f.s. flood is estimated to cause damages of about $43,000 and a 400 c.f.s. flood, about $3,900. In each case damage should be increased by 19 percent to allow for future development.

Table 6d -Summary of damages for 5,000 c.f.s. flood in Etiwanda area (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Agriculture	257,700	51,600	309,300
Business, residential, Federal	18,800	5,600	24,400
Highways and bridges	45,400	9,100	54,500
Railroads and bridges	5,700	3,200	8,900
Utilities	16,200	6,400	22,600
Total	343,800	75,900	419,700

c. San Sevaine Area.--For a flood of 380 c.f.s., damage is estimated at $21,300. Estimated future development will increase the damage about 19 percent.

Table 6e -Summary of damages for 800 c.f.s. flood in San Sevaine area (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Agriculture	119,700	24,000	143,700
Business, residential, Federal	3,100	900	4,000
Highways and bridges	18,500	3,700	22,200
Railroads and bridges	6,800	3,700	10,500
Utilities	23,100	9,200	32,300
Channel improvements	1,800	0	1,800
Total	173,000	41,500	214,500

d. Other frontal canyons.--For the small streams mingling with those of Deer, Day, and Cucamonga damage appraisals have been made by using corresponding discharges on Cucamonga. The estimated damages are $207,600 with a discharge of 10,300 c.f.s.; $20,300 with a discharge of 1,400 c.f.s., and $10,900 with a discharge of 480 c.f.s. Future development will increase damages about 19 percent. These flows debauch from the steep frontal hills upon highly developed citrus areas. In addition, damage to road systems results in costly annual maintenance. Damage to other property is insignificant.

Lytle Creek.--Existing projects of the Corps of Engineers protect Colton and parts of San Bernardino which were repeatedly damaged by the combined flows of Lytle Creek and Cajon Canyon. Damage from floods will continue in the canyons. In Lytle Creek the damage is principally to summer cabins, resorts, power developments, and roads. The 1938 flood destroyed 160 out of 270 cabins and damaged 44. The Lytle Creek area is becoming important for year-long residences because of its cool summers and proximity to the valley cities. Development in the future will be about as intense as it was in 1938.

Estimated damage on Lytle Creek with a flood of 11,500 c.f.s. would be about $574,000. Floods less than 1,500 c.f.s. would cause little or no damage.

Table 6f -Summary of damages for a 25,200 c.f.s. flood above existing structures, Lytle Creek (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Resorts	132,700	47,800	180,500
Cabins	323,500	48,500	372,000
Water companies	96,300	4,800	101,100
Power companies	217,500	10,900	228,400
Public property	118,500	2,400	120,900
State and county roads	126,500	19,000	145,500
Total	1,015,000	133,400	1,148,400

Cajon Canyon.--This canyon is significant as a passageway for transcontinental railroads and highways to the eastern and southern United States. Damages to railroads and highways outweigh all other since little other development exists.

A flood of 11,000 c.f.s. in Cajon Canyon would cause about $920,000 damage. Damage would be negligible from floods less than 2,000 c.f.s.

Table 6g -Summary of damage of 14,500 c.f.s. flood on Cajon Creek (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Agriculture	18,800	3,700	22,500
Residential, business	5,600	1,700	7,300
Electric company	22,200	1,100	23,300
Water company	50,700	2,500	53,200
Railroad and bridges	416,800	416,800	833,600
Highways and bridges	333,700	100,100	433,800
Public property	20,600	400	21,000
Total	868,400	526,300	1,394,700

Cable and Devil Canyons.--These two streams traverse undeveloped cones above authorized Corps of Engineers' structures. Therefore, future damage is expected to be limited largely to highways, scattered residential development, and water-spreading works.

A detailed estimate has been made on Devil Canyon for a flood of the 1938 size or about 3,320 c.f.s. based on 1946 values and development.

Table 6h -Summary of damages for 3,320 c.f.s. flood in Devil Canyon with corresponding flow in Cable Canyon (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Residential and business	12,100	3,600	15,700
Utilities	5,100	300	5,400
Highways and bridges	170,700	34,100	204,800
Channels and spreading grounds	23,700	0	23,700
Total	211,600	38,000	249,600

A flow of 642 c.f.s. on Devil Canyon, with a corresponding flow from Cable Canyon, would cause an estimated damage of about $7,500. No damage is expected from flows less than 200 c.f.s. on Devil Canyon.

Waterman and Strawberry Canyons.--The Corps of Engineers proposes a levee system to protect the outskirts of San Bernardino from the flood waters of Waterman and Strawberry Canyons. Nevertheless, considerable property damage would continue at and above the canyon mouth; largely to roads, cabins, and spreading grounds.

Damage from floods of 2,350 c.f.s. in Waterman and corresponding flows in Strawberry Canyon are given in table i.

Table 6i -Summary of damages for discharge of 2,350 c.f.s. in Waterman and corresponding flow in Strawberry Canyon (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Residential and cabins	66,100	13,200	79,300
Utilities	8,200	400	8,600
Water companies	1,100	100	1,200
Railroads	2,900	300	3,200
Spreading systems	73,300	0	73,300
Roads	189,100	28,400	217,500
Total	340,700	42,400	383,100

A flow of 620 c.f.s. in Waterman and a corresponding flow in Strawberry would cause an estimated damage of about $13,600. Little or no damage is expected from flows less than 200 c.f.s.

Sand, Little Sand, and Borea.--These three creeks traverse citrus groves on their way to Warm Creek. The large debris loads carried cause unstable and shifting channels. Orchards are scoured and fertile topsoil covered by deep sand deposits which necessitate replacement of irrigation pipelines and removal of sand from around trees. Also, streets and roads are covered with deep sand deposits. Desilting basins built at the mouth of the canyons by the county eliminate some of these damages. Damages for a 290 c.f.s. flood on Little Sand, with corresponding discharges on Sand and Borea, are given in table j.

Table 6j -Summary of damages for 290 c.f.s. flood on Little Sand, with corresponding discharges on Sand and Borea (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Agriculture	59,400	11,900	71,300
Residential and business	9,000	2,700	11,700
Railroads and bridges	600	0	600
Highways and bridges	20,700	4,100	24,800
Total	89,700	18,700	108,400

Damage for a 145 c.f.s. flood on Little Sand and corresponding discharges on Sand and Borea were estimated at about $37,800; for 15 c.f.s., $2,500. Damages should be increased by 19 percent to allow for future development.

City Creek.--This channel is deeply entrenched in the upper cone. On the lower cone the county has constructed a levee to control the stream in its westward trend. In the wide entrenched section of the upper cone a few orchards are exposed but will be damaged only when the channel is blocked by debris.

Major damage may be expected to roads, and large flows will affect utilities and the railroad.

Table 6k -Summary of damages for a 6,900 c.f.s. flood, City Creek (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Roads	38,100	5,700	43,800
Railroads	1,000	100	1,100
Utilities	8,400	400	8,800
Total	47,500	6,200	53,700

Damage from a 1,000 c.f.s. flow is estimated to be about $11,000, and from a 600 c.f.s. flow about $1,600.

Santa Ana River Above Mentone.--This area includes all tributaries from City Creek to Mill Creek but not including Mill Creek. The area is largely mountainous. Canyon bottoms and lake areas have been developed with cabins and camp grounds. Near the mouth of Plunge Creek small areas of agricultural land are subject to damage. Part of the wide wash below the mouth is used for water spreading. Roads frequently cross and follow the river and its tributaries. All are vulnerable to flood flows.

Table 61 --Summary of damages for a 52,300 c.f.s. flood on Santa Ana River near Mentone (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Agriculture	23,500	4,700	28,200
Residences	55,100	11,000	66,100
Utilities and water systems	6,500	300	6,800
Railroads	15,900	1,600	17,500
Highways and bridges	205,400	30,800	236,200
Public property	47,000	900	47,900
Total	353,400	49,300	402,700

A flow of 29,100 c.f.s. would cause about $121,000 damage, while flows less than 8,000 c.f.s. are expected to cause insignificant damage.

Mill Creek.--Development below the mouth of the canyon is protected now by a dike which will be lengthened and strengthened under the Corps of Engineers authorized project. Damage above the dike will continue to occur. Mill Creek is one of the important recreational areas of the south with about 700 private cabins in addition to commercial resorts and public camping grounds. Most of these are built on cones formed by very steep side tributaries. Flows from these tributaries are heavily laden with debris, resembling mud-rock flows. Their course is completely unpredictable, and damage to structures and roads is heavy. Some cabins are threatened by Mill Creek proper as well as its tributaries. The threat from Mill Creek has lessened since 1938 when most cabins along the channel were destroyed. Estimates of damage for flows of 18,000 c.f.s. and 6,750 c.f.s. are shown below. Little damage is expected in the area from storms causing discharges of less than 1,000 c.f.s.

Table 6m -Summary of damages for 18,000 c.f.s. flood, Mill Creek (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Resorts	114,600	40,100	154,700
Cabins	256,600	5,100	261,700
Utilities	141,600	14,200	155,800
Fisheries	203,800	20,400	224,200
Water companies	40,700	8,100	48,800
Public property	30,000	300	30,300
Roads and bridges	201,400	10,000	211,400
Total	988,700	98,200	1,086,900

Damage from a 6,750 c.f.s. flow was estimated at $310,000.

Sycamore Canyon.--Water and debris from Sycamore Creek spread over farmland and suburban development. No perceptible channel exists until floodwaters reach Devils Creek. Past residential development has been scattered,which is characteristic of many undefined channel areas. Recent residential tract developments will increase the flood damage in the future. Future damage will be largely to residences, roads and utilities.

Table 6n-Summary of damages for two flood sizes, Sycamore Canyon (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Residences	31,600	9,500	41,100
Roads and streets	22,500	4,500	27,000
Utilities	9,100	900	10,000
Total for 1,200 c.f.s. flood	63,200	14,900	78,100
Residences	12,400	4,000	16,400
Roads and streets	8,600	2,000	10,600
Utilities	7,000	700	7,700
Total for 500 c.f.s. flood	28,000	6,700	34,700

Floods less than 50 c.f.s. are not expected to be damaging. Further development of the area will increase damage by 50 percent.

Jurupa Hills.--Numerous large gullies originating in the Jurupa Hills annually deposit sediment on a 500-foot section of the road. The abnormal maintenance cost of this road has necessitated raising the roadbed. Continued activity of these gullies will result in further road damage within a few years when the debris cone has built up to the present height of the road. About 1,000 cubic yards of debris a year will have to be removed from the road at 50 cents a cubic yard. The average damage is estimated to be $500 a year.

San Timoteo Creek Drainage.--This drainage includes San Timoteo Creek proper and the major tributaries, Edgar (Little San Gorgonio), Noble, Marshall, Olive, Wildwood, Wilson, and Potato Creeks. San Timoteo Creek traverses a narrow valley, broadening in the lower reaches before joining the Santa Ana River. The tributaries drain the Yucaipa-Beaumont plain.

a. San Timoteo Creek. This creek is fairly well entrenched except in its lower reach. Damage in that portion is widespread. A transcontinental railroad and a secondary highway follow the creek and have been cut by almost every high flow. Farmland is lost through bank cutting along the whole course of the stream. All damages recorded after the 1938 flood were adjusted to present conditions, and values are given in table o for a similar flood

Table 6o -Summary of damages for 7,460 c.f.s. flood, San Timoteo drainage (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Residences	16,300	4,800	21,100
Business and industry	17,800	4,500	22,300
Agriculture	54,600	10,900	65,500
Highways and bridges	115,600	4,600	120,200
Railroads and bridges	175,900	35,200	211,100
Water systems	23,100	9,200	32,300
Utilities	1,000	100	1,100
Sewer systems	12,900	0	12,900
Emergency expense	0	1,600	1,600
Total	417,200	70,900	488,100

Estimates for other floods are: 5,000 c.f.s., $180,000; 3,600 c.f.s., $101,000; 1,800 c.f.s., $25,000.

It is estimated that future development will increase damages by 14 percent.

b. Edgar (Little San Gorgonio), Noble, and Marshall Creeks.--These three creeks traverse an area of orchards and grain fields. Channels are intermittently entrenched and partly improved. Estimates of flood damages on these creeks were made for three flows with discharges corresponding to those of 7,460 c.f.s., 3,200 c.f.s., and 1,600 c.f.s. on San Timoteo Creek.

Table 6p -Summary of damages for a 7,460 c.f.s. flood, Edgar, Noble, and Marshall Creeks (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Agriculture	139,200	27,800	167,000
Business and residential	7,200	2,200	9,400
Roads and bridges	30,000	6,000	36,000
Railroads	10,000	10,000	20,000
Utilities	40,000	4,000	44,000
Total	226,400	50,000	276,400

Damage for the other two flood sizes would be: 3,200 c.f.s. on San Timoteo $108,500; 1,600 c.f.s. on San Timoteo $16,400.

Future development, mainly residential, will increase the damage by 20 percent.

c. Olive Creek.--Olive Creek traverses largely deciduous orchards throughout its course. The channel parallels the main road and crosses numerous side roads. A few residences also are affected by overflow from the stream.

Table 6q -Summary of damages for 620 c.f.s. flood, Olive Creek (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Agriculture and residences	13,900	4,200	18,100
Roads	6,000	1,200	7,200
Total	19,900	5,400	25,300

A flow of 310 c.f.s. would do about $10,000 damage and a flow of 130 c.f.s. would cause a $1,000 loss.

Residences and subsistence farms are increasing, which in the future will increase damages by about 20 percent.

d. Wildwood Canyon (Liveoak).--The creek has formed a wide, deep arroyo for a major portion of its course. At its confluence with Wilson Creek it passes through a small urban development without forming a distinct channel. The bottomland of the arroyo, largely in deciduous fruit, is threatened by the overflow of the stream. Cropland is lost from bank cutting and road crossings are damaged. Utilities, mostly water developments, are also damaged by flows.

Table 6r -Summary of damages for a 2,160 c.f.s. flood, Wildwood Canyon (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Agriculture and residences	15,600	3,100	18,700
Roads	11,000	2,200	13,200
Utilities	4,500	500	5,000
Total	31,100	5,800	36,900

Damage for a flow of 1,080 c.f.s. is estimated to be $22,150, and for a flow of 540 c.f.s. $4,400.

Wasteland in the upper section of the arroyo is being improved and planted to fruit which is replacing grain throughout the length of the creek bottomland. The number of residences is also increasing. All of this will increase future damage about 20 percent.

e. Wilson and Potato Creeks.--The valley formation and development of the overflow area of Wilson and Potato Creeks are similar to that of Wildwood.

Table 6s -Summary of damages for a 2,260 c.f.s. flood, Wilson and Potato Creeks (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Agriculture and residences	35,000	7,000	42,000
Roads	14,000	2,800	16,800
Utilities	10,000	1,000	11,000
Total	59,000	10,800	69,800

For a flow of 1,130 c.f.s. the damage would be $24,000 and for 570 c.f.s. $8,000.

Future development will increase damages by about 15 percent.

San Jacinto Drainage.--Structures recommended by the Corps of Engineers will eliminate most of the damage in and around Hemet as well as in the town of San Jacinto. The area downstream from the town of San Jacinto is protected by dikes which are endangered by the enormous debris deposits from Potrero Creek at its junction with San Jacinto. Deposits carried by flows above 4,300 c.f.s. on Potrero Creek are expected to block the San Jacinto River and deflect the flows against the dikes. In this event, the dike may be expected to be breached. The overflow area is entirely agricultural with irrigated pasture, potatoes, and grains the major crops. Damage has been estimated for four flood sizes, namely, 11,000 c.f.s., 4,400 c.f.s., 4,300 c.f.s., and 2,500 c.f.s.

Table 6t -Summary of damages for two flood flows, San Jacinto River at Potrero Creek junction (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Agriculture	226,600	45,300	271,900
Roads	7,600	2,300	9,900
Channel improvement	60,000	0	60,000
Total for 11,000 c.f.s. flood	294,200	47,600	341,800
Agriculture	112,800	22,600	135,400
Roads	4,500	1,300	5,800
Channel improvement	60,000	0	60,000
Total for 4,400 c.f.s. flood	177,300	23,900	201,200

A flow of 4,300 c.f.s. would cause $5,300 damage, and a flow of 2,500 c.f.s. would cause a loss of $3,000. There are now 300 acres of land at the mouth of the canyon which could be reclaimed if the heavy debris flows of Potrero Creek were eliminated. This land would have an estimated value of $200 an acre.

Lamb Creek.--Lamb Creek transports heavy debris loads from its gullied headwaters which are endangering the agricultural land south of Beaumont. Gullies are headcutting into the agricultural land and undermining roads which require numerous relocations. Average annual damage has been estimated at $280.

Perris Valley Drainage.--Two drainage ways originating in the Box Springs Mountains flow into Perris Valley crossing dry-farmed cropland throughout the major length of their courses. The westerly course is the more important since it carries in addition to its own waters the runoff from two military establishments--Camp Haan and March Field. The stream forms a deep channel on the eastern border of March Field to accommodate itself to the depth of the drainage ditches from March Field. After leaving March Field the channel is discontinued and the waters meander over a broad area of cropland. In its course it removes the thin layer of fertile topsoil. This has resulted in reduced grain yields. Irrigated cropland, orchards, and some residential properties are flooded as the stream meanders through the valley.

Damage from the western channel was estimated for discharges of 3,000 c.f.s., 2,250 c.f.s., and 1,200 c.f.s.

Table 6u -Summary of damages for 3,000 c.f.s. flood, Perris Valley, western channel (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Agriculture	47,000	9,400	56,400
Residences	2,400	400	2,800
Roads and highways	5,400	1,100	6,500
Total	54,800	10,900	65,700

Damages for a 2,250 c.f.s. flow were estimated to be $40,000 and for a flow of 1,200 c.f.s., $17,000.

Reche Canyon--Reche Canyon originates in Box Springs Mountains and flows into the Santa Ana River near Colton. Although a minor stream, its flood flows damage roads, buildings, and some farming land.

Near its confluence with the Santa Ana it forms a small valley, planted to alfalfa, citrus, melons, and grains.

Table 6v -Summary of damages for two floods, Reche Canyon (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Agriculture and buildings	9,000	1,800	10,800
Roads	750	150	900
Water and utilities	1,000	100	1,100
Total for 520 c.f.s. flood	10,750	2,050	12,800
Agriculture	1,250	250	1,500
Roads	150	30	180
Water systems	200	40	240
Total for 200 c.f.s. flood	1,600	320	1,920

Highgrove Drainage Area.--Waters from the Highgrove area, adjacent to Riverside, collect in a residential area, draining slowly into the Santa Ana River. Existing ditches of varying capacities carry off some of the water but do not permit unrestricted flow. Damage is caused by flooding houses and roads and by disrupting facilities.

Estimated damages for a 600 c.f.s. flow are $127,000, allowing a 40 percent increase in damage to residential properties due to future development. Damages are estimated to be $32,000 for a flow of 250 c.f.s.

Table 6w -Summary of damages for a 600 c.f.s. flood,Highgrove area (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Business and residences	60,700	12,000	72,700
Roads and streets	10,000	2,000	12,000
Utilities	5,000	1,000	6,000
Total	75,700	15,000	90,700

The Arlington Area.--The floodwater disposal system in the local drainage area around Arlington is poorly defined. Water accumulating from citrus land and low hills flows through intensively developed land to a low, flat area west of Arlington along Highway 18 where it frequently inundates the highway and large blocks of agricultural land. On the sloping land, damage occurs from erosion and deposition while inundation and sediment damage occur to crops, orchards, buildings, irrigation canals, streets, highway and railroad in the lower area. On an average, 400 acres of crop and orchard and 600 buildings are estimated to be affected annually. Total average annual damage has been estimated to be $41,600.

Corona Area.--Hagador and Tin Mine, Eagle and Main Street Canyons, tributary to Temescal Wash, cause damage to the city of Corono and nearby orchards as indicated in table 25.

Table 6x -Summary of damages for various flood flows, Hagador, Tin Mine, Eagle, and Main Street Canyons (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Hagador and Tin Mine			
Agriculture	4,100	800	4,900
Residences and industries	7,100	2,000	9,100
Streets	28,000	5,500	33,500
Total for 700 c.f.s. flood	39,200	8,300	47,500
500 c.f.s. flood			17,000
150 c.f.s. flood			9,000
Eagle and Main Street Canyons			
Agriculture	12,800	2,500	15,300
Streets	27,200	5,000	32,200
Total for 510 c.f.s. flood	40,000	7,500	47,500
400 c.f.s. flood			27,000
200 c.f.s. flood			10,000

Lower Santa Ana Canyon.--Damage is caused in many places by accumulation of floodwater and sediment from local runoff. Extensive damage occurs to citrus groves, highways, railroads, and improvements as a result of inundation and deposition.

Estimated damages for various discharges for three of these locations are given in table y.

Table 6y -Summary of damages for various flood flows, Halladay, Yorba Linda School, and Richfield Creeks (1946 values)

Property damaged	Direct	Indirect	Total
	Dollars	Dollars	Dollars
Halladay Creek			
Agriculture	19,200	4,000	23,200
Railroads	5,000	2,500	7,500
Highways	2,000	500	2,500
Total for 500 c.f.s. flood	26,200	7,000	33,200
200 c.f.s. flood			15,000
Yorba Linda School Creek			
Agriculture	48,000	9,600	57,600
Railroads	10,000	5,000	15,000
Highways	12,000	2,400	14,400
Total for 400 c.f.s. flood	70,000	17,000	87,000
200 c.f.s. flood			25,000
Richfield Creek			
Agriculture	40,000	8,000	48,000
Industrial	14,000	2,800	16,800
Roads	5,000	500	5,500
Railroads	5,000	2,500	7,500
Utilities	8,000	800	8,800
Total for 500 c.f.s. flood	72,000	14,600	86,600
200 c.f.s. flood			25,000

These areas are fully developed and no increase in future damages is expected.

Santa Ana Coastal Plain.--The Villa Park area north of Orange experiences similar damages to those shown for the Halladay, Yorba Linda School, and Richfield areas. The annual damage is estimated to be $10,700.

An area of about 3,000 acres between Anaheim and Anaheim Bay suffers from repeated overflow from waters accumulating in this area and city streets of southwest Anaheim. Citrus orchards near Anaheim and vegetable land along the major portion of the water course are damaged. The average annual damage is estimated to be $44,800.

About 1,500 acres of vegetable land between Garden Grove and the Bolsa Bay are inundated by waters from local accumulation and the city streets of Garden Grove. The average annual damage from these flows is about $30,600.

South of Tustin about 1,900 acres of citrus groves, vegetable land, and naval installations are affected by spreading local and hill runoff. These waters cause annually about $17,800 damage.

Drainage difficulties north of Costa Mesa cause damage to irrigated pasture, alfalfa, and scattered residential development. The annual damage averages $1,100.

FUTURE AVERAGE ANNUAL SEDIMENT DAMAGE

The extent to which sedimentation of reservoirs, debris basins, and channels will add to future damages will depend upon the way sediment will be disposed of. Some sediment is now removed by sluicing from the large reservoirs under the administration of the Los Angeles Flood Control District. The District administration believes that with special installations and favorable water supplies up to 75 percent of all sediment can ultimately be removed by sluicing from the San Gabriel River reservoirs. The material could then be taken out of the channels in easily accessible places and possibly sold as sand and gravel. The Corps of Engineers has just closed a contract by which a sand and gravel pit will be operated in the reservoir basin of the Santa Fe Dam. From debris basins and shallow reservoirs debris has been removed in the past and will continue to be removed by mechanical means. Costs of mechanical removal of sediment from 49 debris basins and small reservoirs in southern California during 1936 to 1940 were about 31 cents a cubic yard. 4/ The cost was as low as 19 cents a cubic yard for an easily accessible debris basin and as high as 92 cents a cubic yard for a small reservoir. It would be about twice as high at present costs and would continue to increase since fewer and fewer dumping grounds are available near the basin sites.

The enormity of the debris problem is best illustrated by the data on reservoir sedimentation shown in Appendix 1, table 8. During the 1938 flood alone 11 1/2 million cubic yards of sediment were deposited in seven reservoirs of the San Gabriel watershed. (Appendix 1, table 7.)

4/ From Los Angeles County Flood Control District records, transmitted by letter of Nov. 27, 1941, file No. 2-11, from H. E. Hedger, Chief Engineer to J. H. Lawrence, Executive Secretary. U.S.D.A. Flood Control Coordinating Committee.

Calculation of future sediment depositions were made for reservoirs, debris basins, and channels in the San Gabriel and Santa Ana watersheds. The methods for calculation are shown in Appendix 2. The estimated average annual amounts for given basins and drainages in the San Gabriel watershed are shown in table 7. In the Santa Ana watershed they are given in table 8.

Table 7.- Estimated future annual sediment deposition to reservoirs and debris basins, San Gabriel Watershed

Reservoir or basin	Drainage area	Estimated future annual sediment 1/
	Sq. mi.	Cu. yd.
San Gabriel #2	40.42	204,100
San Gabriel #1	161.58	1,144,000
Morris	8.08	21,900
Santa Fe	25.26	86,900
Little Dalton debris	3.03	9,500
Big Dalton	4.49	12,200
Big Dalton debris	2.73	8,000
San Dimas	15.92	54,100
Puddingstone Diversion	2.57	18,200
Whittier Narrows	152.65	280,800
Live Oak	2.30	6,100
Thompson	3.91	11,700
Puddingstone	12.34	29,900
La Brea	23.40	41,500
Carbon	17.90	31,800
Fullerton	3.05	5,400
Total		1,966,100

1/ See Appendix 2 for method of calculation.

It is not possible to judge at present how successful debris disposal by sluicing and sale as gravel will be in the future. The experiences of the counties and the Corps of Engineers will decide whether the 6,000,000 cubic yards annually deposited in reservoirs and channels are going to be of benefit or will constitute a damage. Should it turn out that all deposits will have to be removed mostly by mechanical means and dumped at large disposal grounds the annual cost would be between $5,000,000 and $8,000,000.

Table 8.- Estimated future annual sediment deposition in reservoirs, debris basins, and channels, Santa Ana Watershed

Watershed	Drainage area	Estimated future annual sediment 1/
	Sq. mi.	Cu. yd.
San Antonio	26.7	167,700
Cucamonga	10.1	87,200
Deer	3.7	27,200
Day	4.8	46,900
San Sevaine	1.9	8,800
East Etiwanda	3.1	14,200
Frontal canyons	11.8	30,400
Lytle Creek	47.9	314,200
Cajon	40.9	269,100
Lone Pine	15.3	49,000
Devil	6.2	19,700
Cable front	6.1	16,900
Sycamore	2.2	4,400
Waterman	4.6	22,300
Strawberry	8.6	25,400
Little Sand	1.5	5,700
Sand-Borea	9.0	34,200
City Creek	19.7	63,600
Plunge Creek	16.9	56,300
Santa Ana	144.0	463,700
Mill Creek	43.2	369,400
Wilson-Potato	24.6	34,200
Liveoak	23.4	32,500
West of Noble	1.9	3,600
Edgar--Noble	22.8	49,700
Olive	5.1	8,000
San Timoteo	40.2	57,200
Reche	11.6	18,600
Bautiste	54.5	152,100
San Jacinto	85.5	429,000
Leach	2.6	3,900
Santa Ana (Prado)	1,465.0	879,000
Santiago	63.0	203,500
Lower Santa Ana		
a. Halladay Creek area	2.9	1,700
b. Yerba Linda School Creek	1.7	2,400
c. Richfield Creek area	4.0	4,800
Temescal	135.0	183,600
Total		4,160,100

1/ For method of calculation see Appendix 2.

APPENDIX 4

REMEDIAL MEASURES

San Gabriel and Santa Ana River Watersheds, California

Introduction

The flood problem in the San Gabriel and Santa Ana River watersheds with which this report is concerned is primarily one of accelerated sedimentation in downstream flood-control structures and severe damage to lands and property in small watersheds not considered in the investigations by the Corps of Engineers.

The Department of Agriculture program for this watershed was aimed at those remaining elements essential to the fulfillment of a comprehensive flood-control plan. The objective of the measures considered is focused on the reduction of floodwater damages in the remaining unprotected upstream areas, and the reduction of sedimentation which will reduce the costly maintenance of downstream flood-control works of improvement.

In watersheds such as the San Gabriel and Santa Ana, each with two distinct problem areas--one the mountains and the other the valley agricultural lands, the treatment measures logically fall into two groups. One treats the mountain and hill wild-land problem areas, the other the valley agricultural problem areas.

The wild-land problem area, occupying about 53 percent of the watersheds, is predominantly the brush- and forest-covered rough hill and steep mountain land. The unstable geologic structure, the rugged topography, the ever-present threat of wild fire, and the occurrence of intense cyclonic storms make this area a major floodwater and sediment source. Treatment of this broad problem area should be aimed primarily at reducing downstream sedimentation in reservoirs, debris basins, channels, and on developed property.

The cultivated valley floor and the range and pasture lands in the lower half of the two basins contribute accelerated runoff and erosion to local areas in addition to increasing the magnitude of the flood problem in the lower reaches of the main channels. Here the remedial program is directed toward the control and safe disposal of local floodwaters and the reduction of accelerated erosion.

In the following discussion three intensities of program measures will be discussed: (1) going program, (2) total needed program, and (3) recommended program. The "going" program is the quantities of measures that can be accomplished in a 20-year installation period at the 1949 or "present" rate. The "total needed" program is the total quantities of measures required for rehabilitation of the watersheds, and includes the "going" program quantities of measures. The "recommended" program quantities of measures is that which will remain to be accomplished after allowance for the "going" program. It is the difference between the "total needed" program and the "going" program.

Wild-Land Problem Areas

Proper management, including the treatment of floodwater and sediment source areas in the mountains or wild lands is vital to the highly developed urban and agricultural sections through which flood flows must pass. In the San Gabriel River watershed, Los Angeles County's system of seven reservoirs formerly provided the only direct means for reducing flood damages downstream. Subsequent development in both the San Gabriel and Santa Ana basins, by the Corps of Engineers, of a comprehensive system of flood-control basins, debris basins, and improved major channels downstream from the county reservoirs further increased the degree of protecrion afforded valley improvements.

Treatment of the extensive wild-land area above these structures would be aimed at reducing sedimentation which continues to be a serious factor in flood periods. The objectives can be accomplished in large part by intensifying the existing fire control measures and by the treatment of eroding road and highway slopes.

Intensified Fire Protection

Reduction of flood threat and sediment damage can to a large extent be accomplished by maintaining and improving the soil protective wild land cover. An essential element toward accomplishment of this objective is adequate protection against wildfire. This can be obtained by improving fire prevention and control facilities over and above current fire prevention and control measures available to the existing protection organizations. Of the 1,142,800 acres of wild land protected from fire, 60 percent (695,005 acres) is within the national forests under protection of the U. S. Forest Service. The remaining 40 percent is privately owned land for which protection is provided by the California Division of Forestry (386,761 acres) and the Los Angeles County Department of Forester and Fire Warden (61,068 acres). The present level of protection afforded these watershed lands is insufficient to meet flood-control objectives which can be expressed in terms of the maximum allowable burned area and minimum size of fire commensurate with the area and values subject to flood damages. No increase in fire protection measures is anticipated under "going" program so the total program will be the recommended program. In the Santa Ana River watershed the objective is to reduce the average annual rate of burn in the high-hazard zone to approximately two-tenths of 1 percent of the burnable area; in the medium-hazard zone the objective is 0.5 percent. The present average rate of burn for the watershed is about 1.5 percent. In the San Gabriel watershed the objective is to reduce the average annual rate of burn in the high-hazard zone from 0.9 percent to approximately two-tenths of 1 percent of the burnable area.

The future rate of burn with "going" program was estimated from Forest Service records of use of the wild lands, from predicted trends of future use, and from past relations between fire occurrence and number of users. Future use can be expected to increase greatly because of increased population in the report area and subsequent increase in recreational requirements.

A study by the California Division of Forestry shows the relationship between population growth and the incidence of fire for the period 1933 to 1948 as follows:

Year	State population (Millions)	Fire incidence CM zones I and II (Hundreds)
1933	6.0	13
1934	6.1	16
1935	6.2	15
1936	6.3	21
1937	6.4	12
1938	6.8	15
1939	6.9	24
1940	6.9	18
1941	7.1	18
1942	7.4	17
1943	7.8	21
1944	8.3	20
1945	8.8	25
1946	9.3	26
1947	9.7	25
1948	10.0	20

The California Division of Forestry concluded from this study that increased use of the wild-land areas due to the impact of expanding population resulted in a corresponding increase in fire occurrence.

Comparison of the average increase in population with the average increase in forest fire incidence indicates that a 72 percent increase in population was accompanied by an average increase of 69 percent in numbers of fires occurring in zones I and II. For the report area, a 28.2 percent future increase in population is expected for the period 1950 to 1970. Based on past trends a corresponding increase of about 27 percent is expected in numbers of fires for this same period.

The relationship between the area burned annually and the annual number of man-caused fires is shown in the following tabulation for the San Bernardino and Angeles National Forests for the period 1935 through 1950:

Year	San Bernardino National Forest: Man-caused fires	San Bernardino National Forest: Area burned	Angeles National Forest: Man-caused fires	Angeles National Forest: Area burned	Total number of fires in both forests	Total area burned in both forests
	Number	Acres	Number	Acres	Number	Acres
1935	57	320	36	2,582	93	2,902
1936	80	6,162	32	1,506	112	7,668
1937	81	145	50	2,933	131	3,078
1938	40	10,937	34	3,324	74	14,261
1939	30	16	30	222	60	238
1940	45	21,001	44	273	89	21,274
1941	37	3,113	13	158	50	3,271
1942	52	26,275	38	3,343	90	29,618
1943	53	12,543	18	5,317	71	17,860
1944	34	5,113	26	20	60	5,133
1945	94	16,156	42	349	136	16,505
1946	41	887	48	6,873	89	7,760
1947	55	102	68	4,480	123	4,582
1948	59	1,283	55	1,681	114	2,964
1949	81	317	48	16,627	129	16,944
1950	78	1,125	50	8,933	128	10,058
Total					1,549	164,116
Average					97	10,257

At present in the report area the average annual number of man-caused fires is 46 and the corresponding average annual rate of burn is 4,700 acres.

A similar relationship exists in the State and County protected areas shown in the following tabulation for Riverside and San Bernardino Counties:

Year	Man-caused fires (Number)	Annual burned area (Acres)
1933	62	271
1934	46	611
1935	133	3,728
1936	149	5,194
1937	174	13,142
1938	177	21,174
1939	209	42,295
1940	182	24,099
1941	177	21,174
1942	209	42,295
1943	182	24,099
1944	162	49,565
1945	179	43,953
1946	117	5,952
1947	141	7,713
1948	126	2,610
1949	103	2,662
1950	123	4,782

Projection of these data indicates that the number of fires in the national forests can be expected to increase in the future without program from the present number of 46 to about 58. Similarly, the average annual burn should increase to about 19,800 acres. These expected future trends would result in a future average annual rate of burn of 2.85 percent with the present level of protection ("going" program) projected into the future.

For the Clarke-McNary protection areas the number of fires is expected to increase from the present 207 to about 260. Similarly, the average annual burned area is expected to be about 15,600 acres under present protection levels ("going" program). The future rate of burn without the recommended protection will then be 3.5 percent.

The objectives of the recommended fire-protection measures will be to reduce the rate of burn to 0.2 of 1 percent in the high-hazard zone within the national forest and state-county protected areas. The objective for the medium-hazard zone now protected by the State is to reduce the rate of burn to 0.5 of 1 percent. The average over-all objective for the report

area with recommended protection is 0.3 of 1 percent. With these objectives the anticipated annual burned area for the national forests will be 1,400 acres and for the State and County protection zones 1,600 acres.

To accomplish these objectives through a reduction in the size of fires, measures of prevention, detection, and suppression need to be intensified. Added protection should be greatest in the high-hazard frontal mountains of the national forests. Additional facilities required include about 144 units of improved detection and communication measures at an estimated initial cost of $167,300. About 398 miles of roads, trails, and tractor ways are necessary to permit speedire attack on all fires. Construction of roads, trails, and tractor ways is estimated at about $977,300. About 92 water catchment and storage systems are needed to aid in suppressing fires; they are estimated to cost $135,200. Approximately 89 buildings will be required to house equipment and fire-fighting personnel at a construction cost of about $805,100. Additional equipment includes motorized units, tractors, and similar items, estimated to cost about $101,200. Protection personnel, over and above present fire protection personnel, which will be required to operate the recommended fire protection plant includes patrolmen, tank truck and tractor operators, radio operators, and air crews. The annual cost of the new positions is estimated to be about $169,400.

The California Division of Forestry fire protection zones require similar additional facilities in their areas to effect comparable reduction in average annual burn. These additions include about seven buildings and related equipment at an estimated cost of about $137,000, some 12 units of equipment including tank trucks estimated to cost $61,500 and about 36 new positions at an annual cost of $66,200.

That portion of the basin protected by the Los Angeles County Department of Forester and Fire Warden will require 3 additional buildings and related equipment estimated to cost about $37,800; some 47 miles of roads, trails, and tractor ways costing about $118,700; communication and detection units at $5,300; and additional equipment estimated at $10,500.

The annual operation, maintenance, and replacement costs for the national forest area are estimated to be about $253,900. Annual operation, maintenance, and replacement costs for the California Division of Forestry are estimated to be about $105,600; and for Los Angeles County $26,100.

The total estimated installation cost for recommended fire protection and suppression is about $2,561,400. Total annual operation, maintenance, and replacement costs are estimated at about $385,600 (tables 1 and 2).

The protection system as outlined is not static. Therefore, the recommended additions to the present plant may need revision or modification as new techniques and fire-control devices are developed. By reducing the amount of area burned a gradual increase in the age of existing vegetation will result. This in turn means denser cover, hence less runoff and sedimentation.

Table 1.--Installation cost of recommended fir protection, by protection agency

Type	Unit	Forest Service		Los Angeles County		California Division of Forestry		Total	
		No.	Cost	No.	Cost	No.	Cost	No.	Cost
			Dollars		Dollars		Dollars		Dollars
Buildings	Number	89	805,100	3	37,800	7	137,000	99	979,900
Roads, trails, and firebreaks	Miles	398	977,300	47	118,700	--	--	445	1,096,000
Communications	Number	144	167,300	6	5,300	2	1,000	152	173,600
Water developments	Number	92	135,200	10	3,500	--	--	102	138,700
Equipment, etc.	Number	64	101,200	--	10,500	12	61,500		173,200
Total			2,186,100		175,800		199,500		2,561,400

Table 2.--Operation, maintenance, and replacement costs of recommended fire protection by protection agency

Type	Forest Service	Los Angeles County	California Division of Forestry	Total
	Dollars	Dollars	Dollars	Dollars
Buildings	33,600	16,500	17,500	67,600
Roads	12,900	6,000	--	18,900
Communications	10,000	1,000	300	11,300
Water developments	5,000	300	--	5,300
Equipment, etc.	23,000	2,300	21,600	46,900
Personnel	169,400	--	66,200	235,600
Total	253,900	26,100	105,600	385,600

Table 3 shows the location and acreage protected by the U. S. Forest Service, the California Division of Forestry, and Los Angeles County.

Table 3.--Location and size of the areas protected by the three responsible agencies in the San Gabriel-Santa Ana River watersheds

Protection agency	General location	Area of recommended protection
		Acres
California Division of Forestry	Valley hills in Orange, Riverside, and San Bernardino Counties	386,760
Los Angeles County Department of Forester and Fire Warden	Frontal area and valley hills, Los Angeles County	61,069
U. S. Forest Service	San Gabriel, San Bernardino, San Jacinto, and Santa Ana Mountains	695,000
Total		1,142,829

The number of large fires and the total burned area can be reduced but total exclusion of fire cannot be expected within the limits of present knowledge or techniques. To guard against excessive damage from the inevitable fire that will occur in spite of the intensity of protection, Congress has authorized the emergency treatment of such burned areas where threat of flood damage occurs. 1/ An appropriation of $300,000 is made annually to undertake such emergency measures as are necessary. Continued provision for emergency treatment of burns is essential to the over-all objectives of a comprehensive flood-control plan.

Land Acquisition

An essential aid to accomplishing the fire-control objective is the assurance that certain tracts of land located in the extremely high fire-hazard zone receive adequate prevention effort commensurate with protection afforded adjoining lands. Some 63 such tracts, totaling about 15,000 acres, are privately owned within or adjacent to the publicly owned national forests in the Santa Ana watershed. Public acquisition of these scattered tracts will be a direct method of reducing fire occurrence by limiting the present unrestricted use where threat of fire is extremely high and local cooperation limited. Certain of these tracts are significant sediment-source areas which cannot be remedied under present ownership. A few tracts are recommended as essential for the location of facilitating improvements and sediment-control structures dependent upon adequate fire protection of the adjoining watershed lands. The estimated cost of acquiring the 15,000 acres is about $500,000. No acquisition is anticipated under the going program.

1/ Flood Control Act of May 17, 1950.

Road Slope Stabilization

Mechanical and vegetative treatment of actively eroding road-fill slopes needs to be accomplished by improved drainage facilities and stabilization of fill or overcast slopes. Additional adequate drainage structures for the safe disposal of water collecting on and crossing the road will reduce the erosion from and adjacent to the road. Slope fixation of actively eroding fills will be accomplished by a system of contour imbedded wattles, staking in various combinations and spacings best suited to local soil conditions, by mulch covering, or other suitable methods.

Support and protection of the toe of fill slopes, where necessary, will be accomplished by the installation of walls. The immediate control of surface erosion will be obtained by the sowing of cereal grains or other quick-growing annual plants. Final stabilization will be secured by planting suitable trees and shrubs, including cuttings of sprouting shrubs. No increase in road slope stabilization is anticipated under the going program.

Estimated total installation cost to accomplish this phase of the recommended program is about $2,682,700 with an average annual maintenance and replacement cost of $27,400. About 135 acres of fill slopes require treatment and improved drainage is necessary on about 200 miles of roads. (See table 4.)

Table 4.--Estimated installation and annual maintenance costs of recommended program, mountain road slope stabilization, and surface drainage improvement

Area	Area to be treated		Installation	Annual maintenance
	Acres	Miles	Dollars	Dollars
San Gabriel above:				
Dam No. 2	11	34	438,900	4,400
Dam No. 1	30	90	885,000	8,800
Little Dalton Canyon	15	14	115,400	1,200
Frontal area north of Glendora	1	4	41,200	400
Frontal area east of Glendora	1	1	4,700	500
Thompson Creek above dam	4	8	44,000	500
Live Oak above dam	2	2	75,800	800
San Antonio	10	8	198,000	1,990
Waterman--Strawberry	20	15	383,200	3,830
Sand, Borea, Little Sand	11	18	122,200	1,230
City Creek	8	5	162,800	1,630
Mill Creek	20	10	211,500	2,120
Total	133	209	2,682,700	27,400

Revised July 1952

Control of debris is dependent upon the minimum amount of disturbance of adjacent forest cover by fire. Burned areas above roads increase the runoff collecting on and crossing the road, consequently affect the stability of the road slopes and adequacy of drainage structures. Burned fill slopes that have previously been stabilized by vegetation provide ideal sites for the development of erosion gullies.

Valley Agricultural Problem Areas and Their Treatment

Agricultural problem areas requiring treatment to reduce and control flood runoff and erosion are located on the sloping cultivated lands and the range and pasture hill lands in the lower half of the basin. To accomplish reduction and control of flood runoff and erosion under the recommended program requires the improvement of crop and range lands by land management practices and the improvement of small community channels needed to carry floodwaters from small watersheds and farm runoff disposal systems into the larger channels.

Community Channel Improvements

Approximately 560 miles of existing community waterways are in need of improvement to provide adequate capacity for flood flows and stabilization to prevent floodwater and sediment damage. The improvements required include debris basins, stabilization of existing streams, enlargement of inadequate channels, and chanelization of flow on debris fans where agricultural development has encroached upon and practically eliminated any definite stream courses.

The estimated cost of recommended community channel control is based on field examination and estimate of required controls on many valley streams in the watershed. Types of work estimated range from improvements such as debris dams and lined channels along the San Gabriel mountain front to stabilization of existing entrenched gullies with drop structures or revetments, earth sections, concrete conduits, or other works adequate and consistent with control requirements and degree of development in the particular vicinity. All estimates are for major flood capacities and permanent improvement. No increase in community channel improvements is anticipated under the going program.

Slopes from small frontal San Gabriel mountain canyons through reaches tributary to Little Dalton and Big Dalton channels are steep and poorly defined, a characteristic of alluvial fans formed by high debris producing watersheds.

Needed improvements are debris basins and lined channels. The material from the mountainous areas has to be trapped before the floodwater can be passed safely through the highly developed citrus area into the main drainage systems.

Improvements in the area tributary to Walnut Creek between Covina and San Dimas call mainly for increase in the capacity of channels. This will prevent flooding of the intense citrus culture in the area.

The reaches of tributaries of San Jose Creek are on moderate slopes, draining an area almost entirely agricultural. Channel improvements are needed in the valley lands between the San Jose and Puente Hills and San Jose Creek. They include channel stabilization to control erosional activity, increase in channel capacity to prevent flood damage, and provision of adequate disposal outlets for farm runoff.

Along the La Habra and Whittier front in the Puente Hills the problem is one of controlling erosion in the upper reaches of streams and providing adequate channel capacity across the lower slopes to major flood-control channels.

The coastal plains area below existing flood-control dams on Fullerton and Brea Creeks present problems of removal of surface water from all storms. Local agencies have made some improvements on this system, but additional improvements are needed to prevent inundation damage to extensive citrus groves and to local improvements, streets, and utilities.

The Cucamonga-Fontana area is traversed by debris-laden flows from the San Gabriel Mountains augmented by local valley runoff. Measures recommended include improved channels for disposal of floodwaters from the small frontal mountain watersheds and valley source areas.

San Bernardino Valley area is subject to flood and debris damages from many small frontal mountain canyons. Structural measures will include debris basins and permanent channel improvements.

San Timoteo area is a direct contributor of sediment to the Santa Ana River, the natural drainage system is entrenched and an active source of sediment from both gully and sheet erosion. Channel stabilization in the active gully erosion reaches will be accomplished by planting, revetment, bottom stabilizers, and local alignment improvement to reduce sediment production and land loss and to provide a stable outlet system for the farmland treatment measures involving water disposal.

These controls will be essential to accomplish the over-all estimated sediment reduction in Prado Reservoir by treatment of the watershed lands. Major flood damage reduction in the lower reach of San Timoteo can be attained only by flood regulation which has been considered but not recommended by the Corps of Engineers.

Recommended community channel improvement in the San Jacinto River area consists of a number of more or less independent flood-control improvements. The flood pattern of the area tributary to Railroad Canyon Reservoir is over a broad flood plain which prevents siltation of the reservoir. Correction of local problems involves both sediment and water control. Proposals include such measures as small flood-retarding reservoirs, channelization, and channel stabilization with plantings and revetments.

The Corona, Arlington, Riverside area drains into the Santa Ana River near Prado Reservoir. The recommended program involves local problems not considered by the Corps of Engineers. Controls in this intensively developed citrus area include such channelization measures as earth channels with

revetment where necessary for stabilization or lined conduits on steep slopes.

Recommended controls in the tributary areas of the Santa Ana River below Prado Dam are largely channel improvements to remove accumulations of water on relatively flat, intensively developed citrus areas. The sources of water are from adjacent hills and sloping cultivated land.

Recommended controls in the Santa Ana coastal plain are largely channel improvements to remove accumulation of water on flat, intensively developed citrus, truck crop, and suburban areas. The sources of water are from adjacent hills, suburban impervious areas, and the agricultural lands.

The majority of the community channel improvements are recommended to enable installation of the complete land treatment program on agricultural lands, as well as for their direct flood-control benefits. In this group are approximately 520 miles of tributary stream channel and collecting ditches with improvement costs of approximately $22,156,700.

There are other community channel improvements, independent of land treatment, which are recommended for flood damage reduction. Approximately 40 miles of channel improvements, costing approximately $1,635,000, are recommended in this group. The improvements are located largely on the coastal plain area of the Santa Ana watershed.

The total cost for community channel improvement has been derived primarily from two sources. Local county flood-control districts cost summaries for projects considered part of this program have been taken directly from their prepared cost summaries. Additional and necessary supplemental channel improvements have been estimated for individual situations and were extremely variable in character.

The estimated installation cost at 1946-47 price levels of the recommended community channel improvements is about $23,791,700. Annual maintenance costs are estimated at $394,700.

Table 5 indicates the range in predominant unit costs used in estimating cost of improvements at 1946-47 price levels.

Table 5.--Unit cost

Item	Unit	Unit cost
		Dollars
Earth excavation	Cubic yards	.25-.40
Single pipe and wire revetment	Linear feet	1.50
Double pipe and wire revetment	Linear feet	3.50
Rail and wire stabilizers	Linear feet	65.00
Reinforced concrete	Cubic yards	60-75
Bank protection planting	Linear feet	1.00

Crop and Range-Land Improvements

Table 6 shows total agricultural land use by capability class. Table 7 gives the required quantities of primary erosion-control practices for an adequate land-treatment program in the interest of flood control. These are for land conditions existing in 1948 and include work that should be done under going and recommended programs.

Table 6 has been developed from a reconnaissance soil survey of the watershed and land-use data tabulated by small subdivisions of the watershed. Within each land-use reporting area capability class and land use were correlated by field survey.

Description of lands in each capability class is as follows:

Class I: Land is very good with little or no limitation or hazard. It is nearly level, deep, and without erosion. Some of it may need drainage, clearing, or other conditioning measures.

Class II: Land is good with only minor limitations or hazards, such as gentle slopes, moderately shallow soils or slight susceptibility to erosion. Choice in use may be reduced, and conservation practices, such as water management, contour operation, cover cropping, etc., are required.

Class III: Land is moderately good with major physical limitations and hazards. It usually is characterized by relatively steep slopes, shallow soils, or severe erosion problems. Choice in use is limited and protective measures, such as terracing, strip cropping, and careful water management, are necessary.

Class IV: Land is fairly good, suitable for occasional cultivation--usually not more frequently than 1 year in 4. When plowed, considerable care needs to be taken to avoid erosion or other lasting damage.

Class V: Land is very well suited for grazing or forestry. It has little or no physical limitations or hazards when so used, but requires good range or woodland management.

Class VI: Land is well suited for grazing or forestry. It has minor hazards and limitations due to moderately steep slopes, shallow soils or susceptibility to erosion.

Class VII: Land is fairly well suited for grazing or forestry use. It has major hazards or limitations because of very steep slopes, shallow or droughty soils, or advanced erosion.

Class VIII: Land is unsuited for agricultural purposes, but may be used for wildlife, recreational, or watershed purposes.

Table 6.--Agricultural use by land capability classes: San Gabriel-Santa Ana River watersheds

Land use	Land capability class I	II	III	IV	VI	VII	Total
	Acres						
Citrus	61,940	111,180	51,980	9,990	5,500		240,590
Deciduous orchard and vineyard	10,750	50,000	19,190	3,860	410		84,210
Irrigated row and diversified crops	58,680	83,220	14,580				156,480
Cereal hay and grain	3,620	59,070	85,260	20,180	5,930		174,060
Pasture and range		8,230	77,250	38,100	94,620	33,660	251,860
Total	134,990	311,700	248,260	72,130	106,460	33,660	907,200

Table 7.--Total quantities of agricultural land-treatment measures needed under 1948 conditions: San Gabriel-Santa Ana River watersheds

Practice	Unit	Amount
Farm runoff disposal system	Acres	98,730
Terracing and diversion systems	Acres	43,660
Range improvements	Acres	251,860
Grass seeding	Acres	21,830
Annual cover crop	Acres	94,900
Irrigation system improvements	Acres	36,450
Cultural conservation practices	Acres	614,500
Community channel improvements	Miles	560

Estimates of total quantities of conservation measures needed were made from specifications of conservation practices required for each land-use capability class and field estimates of quantities of each practice needed

for control of sediment-producing areas. 2/ These field estimates were to give due consideration to present application of conservation measures and practices.

Total needed measures for waterflow retardation and erosion control on crop and range lands include:

a. Farm Runoff Disposal System.--In the Cucamonga, Fontana, San Bernardino area essential measures to control erosion or sediment production on 13,000 acres of citrus and 17,000 acres of deciduous orchard are farm runoff disposal systems. In other portions of the watershed about 25,100 acres of Class II, III, and IV orchard land are in need of runoff disposal systems.

Improvement of runoff disposal systems in the San Gabriel watershed on from 30 to 80 percent of Class II and 80 percent of Class III, IV, and VI citrus and deciduous orchard and vineyard land is needed on an area of about 41,600 acres. These improvements are in the nature of vegetated waterways, small outlet and channel stabilization structures, lined channels, and pipelines.

This item does not include water disposal on grainland which is considered under "Terrace and Diversion Systems."

b. Grass Seeding.--Approximately 22,000 acres of Classes IV and VI land not suitable for continuous cultivation are now farmed to grain. This land is a critical sediment source and some has, in its 50-year history of cultivation, eroded to the point where cultivation is no longer profitable. Erosion continues under the poor volunteer cover that has become established on the abandoned areas. These areas are to be seeded to permanent pasture grasses to minimize erosion and insure maximum productivity under proper land use. Since this change in land use will involve some temporary loss of income to owners, cost of seed has been assumed as a Federal contribution to induce proper use.

c. Range Improvement.--Range and pasture improvement by controlled grazing and proper stocking is needed on approximately 252,000 acres. This will include fencing, water development, and reseeding. Approximately half the range land in the Santa Ana watershed is in the San Jacinto drainage basin. About three-fourths of the range land is located on the foothill and low mountain slopes where it is adjacent to or accessible from cropland areas in the valley. The remaining one-fourth is located in small, high mountain valleys and adjacent ridges.

The forage types occurring on the foothill areas consist of annual and perennial grasses growing among low-growing, unpalatable shrubs and brush. In the mountain areas small wet meadows occur with the surrounding forage consisting of annual and perennial grasses growing as an under-story to both palatable and unpalatable chaparral type trees and brush species.

2/ Cucamonga, Yucaipa, San Gorgonio Soil Conservation District Technical Guide.

must. table showing acres by measures

The range-land measures needed are directed toward the accomplishment of the following major objectives: (1) the development of adequate water to bring about a uniform use of the range and to relive the stress on localized areas where erosion is occurring due to overgrazing around the limited number of water sources; (2) fencing to make possible the control of season and rate of grazing and to permit protection and improvement of existing cover in a rotation deferred grazing system, also to protect lands not suitable for grazing use from livestock damage; (3) improvement of the better range lands which are less subject to severe erosion and excessive runoff by reseeding, brush control, and grazing management.

Sediment from these lands contributes to damaging deposition in streams, on agricultural land, and other locations.

d. Terracing or Diversion Systems.--These measures are applied primarily to Class II and III grainland and are needed to control some of the most critical erosion and sediment source areas in the watershed. Their application at present is limited to about 44,000 acres because of inadequacy of community outlet channels, control of which is included in community channel improvements.

e. Planting in annual winter cover crops is needed to minimize soil erosion and maintain soil resources and fertility on approximately 95,000 acres of orchard. These areas requiring treatment include about 35 percent of the citrus and deciduous orchards and vineyards.

f. Irrigation improvement for erosion control on 15 percent of Class II, III, and IV irrigated land will prevent excessive contribution of soil from this source to downstream sediment damage areas.

g. Other conservation practices for runoff and erosion control including subsoiling, mulching, contour tillage, basin listing, crop rotation, stubble mulch tillage, better timing of cultural operations with respect to erosion hazards, or other necessary practices primarily in Class I and Class II deciduous orchard and vineyard. Improved cultural practices need to be installed on 615,000 acres or 50 to 80 percent of all citrus and deciduous orchards and vineyards where these practices are applicable.

Crop rotation will be practiced on all irrigated row and diversified croplands and on part of Class I, II, and III cereal hay and grainlands as determined by field survey.

<u>Division of Measures Between "Going" and "Recommended" Programs</u>

The determination of the quantity of recommended measures for the intensification of the present program for both flood control and conservation of watershed lands was made by consideration of total needs and projection of anticipated accomplishment by going programs.

The present rate of application of measures for both flood control and conservation of watershed lands was obtained from the 1949 records of practice payments by the Agricultural Conservation Program of the Production

and Marketing Administration and from Soil Conservation Service records of application of conservation practices applied in the North Orange County Soil Conservation District.

The quantities of measures that can be accomplished in a 20-year installation period, at the 1949 rate, were subtracted from total needs (table 7) to determine the measures and quantities in the program (table 8).

Table 8.--Quantities and costs of recommended agricultural land-treatment measures: San Gabriel-Santa Ana River watersheds 1/

Practice	Quantity	Installation	Annual operation, maintenance, and replacement
		Dollars	Dollars
Farm runoff disposal systems	96,700 acres	1,461,700	57,500
Grass seeding	14,800 acres	310,300	--
Range improvement	235,900 acres	472,800	29,000
Terracing and diversion systems	40,500 acres	775,900	33,300
Community channel improvement	560 miles	23,791,700	394,700
Total		26,812,400	514,500

1/ Technical services, educational assistance, and administration of direct aids for crop- and range-land treatment amounting to about 2 percent of the total installation cost have been included.

It is estimated that about 50 percent of the existing agricultural land-treatment needs will be accomplished by the going program in the San Gabriel watershed and 30 percent in the Santa Ana watershed, leaving 50 percent and 70 percent respectively to be accomplished by the recommended program.

The total installation cost of the recommended crop and range land-treatment measures is $3,020,700. The average annual operation and maintenance cost is $119,800.

Installation of runoff-control measures on the land is often contingent upon improvement of community channels which serve as outlets for disposal of runoff. The improvement of these interdependent channels is considered an integral part of the farm-land treatment program.

The total estimated installation cost of recommended crop and range land improvements and related community channel improvements is about $25,177,400. Annual maintenance costs are about $468,000.

Recommended independent community channel improvements have an installation cost of $1,635,000 and annual maintenance cost of $46,500.

Total cost of installation of the measures recommended for the crop and range-land area, including the independent community channel improvements, is $26,812,400. Operation, maintenance, and replacement of these measures is estimated to be $514,500 annually.

Physical Benefits of the Recommended Measures

The primary objectivesof the wild land, range, and cropland measures recommended in this report are:

1. To increase infiltration and reduce damaging soil erosion by protecting the soils against high intensity rains.

2. To increase the effectiveness of the land-use measures by supplemental structures on the land.

The estimated effects of the land-use measures in terms of reduced run-off and erosion rates are given in table 9. Improvement in cover conditions reduces not only the stream discharges but also the amount of sediment yielded by the streams.

The combined physical effect of all measures results in a reduction of about 50 percent in flood damages.

Sediment reduction by the programs will amount to about 34,450 cubic yards annually.

In addition to the flood damage reduction benefits, a series of associated benefits also will accrue.

Reduction in the number of damaging wildfires and the shift toward smaller fires will be reflected in reduced fire suppression costs and loss of property by fire. These effects will accrue coincident with the installation of the fire-control improvements.

Better grassland cover and improved pasture management will gradually increase the grazing capacity of the land.

Cropland measures will prevent a decline in soil fertility, and will maintain yields at or above present levels. Thus the income of farmers will be maintained and the agriculture of the watershed stabilized.

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Table 9.--Estimated sediment and peak discharge reductions with and without the recommended program 1/

Sub-watershed	Drainage area	Rates without program: Sediment	Rates without program: 100-yr. flood	Rates with program: Sediment	Rates with program: 100-yr. flood	Reduction: Sediment		Reduction: 100-yr. flood discharge	
	Sq.mi.	C.y./sq. mi./yr.	C.f.s.	C.y./sq. mi./yr.	C.f.s.	C.y./sq. mi./yr.	Percent	C.f.s.	Percent
San Antonio	26.7	6,280	12,800	5,490	12,200	790	13.0	600	4.7
Cucamonga	10.1	8,630	9,900	7,460	9,300	1,170	13.5	600	6.1
Deer	3.7	7,340	3,270	6,120	3,030	1,220	16.6	240	7.3
Day	4.8	9,770	3,020	8,280	2,820	1,490	15.2	200	6.6
San Sevaine	1.9	4,620	780	3,850	730	770	16.7	50	6.4
East Etiwanda	3.1	4,590	1,310	3,870	1,220	720	15.7	90	6.9
Cucamonga Front	11.8	2,580	--	2,060	--	520	20.1	--	--
Lytle Creek	47.9	6,560	21,200	5,850	20,200	710	10.8	1,000	4.7
Cajon	40.9	6,580	15,600	5,260	14,300	1,320	20.1	1,300	8.3
Lone Pine	15.3	3,200	5,500	2,640	5,100	560	17.5	400	7.3
Devil	6.2	3,180	2,840	2,670	2,640	510	16.0	200	7.6
Cable Front	6.1	2,770	--	2,330	--	440	15.9	--	--
Sycamore	2.2	2,005	1,000	1,680	930	325	16.2	70	7.0
Waterman	4.6	4,840	2,100	3,900	1,970	940	19.0	230	10.9
Strawberry	8.6	2,950	3,240	2,430	3,070	520	18.0	170	5.3
Little Sand	1.5	3,800	460	2,300	410	1,500	40.0	50	10.9
Sand, Borea, etc.	9.0	3,800	--	2,700	--	1,100	29.0	--	--
City Creek	19.7	3,230	6,130	2,410	5,660	820	24.0	470	7.7
Plunge Creek	16.9	3,330	4,760	2,770	4,390	560	16.8	370	7.8
Santa Ana	144.0	3,220	55,400	2,950	53,400	270	8.4	2,000	3.6
Mill Creek	43.2	8,550	16,900	7,410	16,200	1,140	13.0	700	4.1
Wilson—Potato	24.6	1,390	2,300	1,120	2,090	270	19.4	210	9.1
Liveoak	23.4	1,390	2,220	1,120	2,020	270	19.4	200	9.0
West of Noble	1.9	1,900	--	1,900	--	--	--	--	--
Edgar-Noble	22.8	2,180	6,640	1,760	6,040	420	19.3	600	9.0
Olive	5.1	1,570	630	1,265	570	305	19.4	60	9.5
San Timoteo	40.2	1,423	2/7,650	7,354	2/6,970	296	20.8	2/680	8.9
Potrero	31.0	7,430	16,500	5,000	13,900	2,430	33.0	2,600	15.8
Reche	11.6	1,600	650	1,088	550	512	32.0	100	15.4
Bautiste	54.5	2,790	24,200	2,220	21,700	570	20.4	2,500	10.3
San Jacinto	85.5	5,017	3/59,400	3,972	3/53,800	1,045	20.8	3/5,600	9.4
Leach	2.6	1,500	360	1,295	350	205	13.7	10	2.8
Hagador--Tin Mine	5.6	1,500	770	1,295	760	205	13.7	10	1.3
Highgrove	4.8	1,320	610	1,060	550	260	19.7	60	9.8
Main-Eagle	4.3	1,500	605	1,295	595	205	13.7	10	1.6

Continued

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Table 9.--Estimated sediment and peak discharge reductions with and without the recommended program - Contd.

Sub-watershed	Drainage area	Rates without program: Sediment	Rates without program: 100-yr. flood	Rates with program: Sediment	Rates with program: 100-yr. flood	Reduction: Sediment		Reduction: 100-yr. flood discharge	
	Sq.mi	C.y./sq mi./yr.	C.f.s.	C.y./sq. mi./yr.	C.f.s.	C.y./sq. mi./yr.	Per-cent	C.f.s.	Per-cent
Prado	1,465.0	600	97,200	495	91,000	105	17.5	6,200	6.4
Santiago	63.0	3,230	12,900	2,600	11,700	630	19.5	1,200	9.3
Lower Santa Ana									
a.	2.9	1,700	--	1,500	--	200	11.8	--	--
b.	1.7	1,400	--	1,200	--	200	14.3	--	--
c.	4.0	1,200	--	1,000	--	200	16.7	--	--
Temescal	135.0	1,360	15,100	1,090	13,600	270	19.8	2,500	16.5
San Gabriel #2	40.4	5,050	24,900	3,950	24,100	1,100	20.0	800	3.2
San Gabriel #1	161.6	7,080	4/80,900	6,100	79,500	980	14.0	1,400	1.7
Morris	8.1	2,710	5/	2,435	--	275	10.1	--	--
Santa Fe	25.3	3,440	5/	3,000	--	440	12.8	--	--
Little Dalton debris	3.0	3,150	770	1,760	740	1,390	44.0	30	3.8
Big Dalton	4.5	2,710	1,140	2,435	1,080	275	10.1	60	5.3
Big Dalton debris	2.7	2,930	700	2,620	670	310	10.6	30	4.3
San Dimas	15.9	3,400	4,400	3,080	4,200	320	9.4	200	4.5
Puddingstone Diversion	2.6	7,070	5,030	6,500	4,650	570	8.1	380	7.5
Whittier Narrows	152.6	1,839	5/	1,590	--	249	13.0	--	--
Live Oak	2.3	2,650	310	1,970	290	680	25.0	20	6.5
Thompson Creek	3.9	2,980	560	2,425	530	555	18.0	30	5.3
Puddingstone	12.3	2,420	5,280	2,090	4,980	330	13.6	300	5.7
La Brea	23.4	1,775	5/	1,540	--	235	13.0	--	--
Carbon	17.9	1,775	5/	1,502	--	273	15.0	--	--
Fullerton	3.0	1,775	5/	1,300	--	475	25.0	--	--

1/ See Appendix 2 for method of calculation.

2/ For 118 squre miles.

3/ For 140 square miles.

4/ For 202 square miles.

5/ Not calculated.

UNITED STATES DEPARTMENT OF AGRICULTURE

APPENDIX 5

PROGRAM APPRAISAL

San Gabriel and Santa Ana River Watersheds, California

To accompany report on survey, flood control,
San Gabriel and Santa Ana River Watersheds, California

APPENDIX 5

PROGRAM APPRAISAL

The remedial program is aimed at restoring and maintaining the maximum infiltration rates compatible with use of the watersheds and within the limits of economic justification. The program also seeks to reduce the accelerated erosion which results in decreased channel capacities, impairs the value of flood control and water storage developments, and generally augments the damage caused by flood impact and inundation.

Previous appendices have described the various measures designed to reduce runoff and erosion from wild, range, and crop lands. Their effect on peak discharges is shown in table 9, Appendix 4. Associated benefits of a wide variety also will accrue from the recommended program. In addition to these direct benefits the program will return benefits which are definite but difficult to evaluate.

Benefits and costs were estimated on the assumption of complete installation of measures and full participation of local interests, both public and private. A high degree of cooperation in the range and cultivated land measures is expected in view of the present attitude and participation of farmers and ranchers in existing public programs. All monetary values are in terms of prices prevailing in 1946-47 for the Santa Ana and San Gabriel watersheds, respectively.

Analysis of Benefits

Flood Damage Reduction Benefits.--Reduction of flood damages by the recommended program is estimated to be about $490,800 annually. The flood damage reductions were based on data presented in Appendices 2, 3, and 4. These evaluated flood-damage reductions can be attributed mainly but not entirely to the combined effects of improved community channels, intensified forest fire control and crop and range land-treatment measures. In the open-land areas the interdependent channel and crop land improvement measures will prevent uncontrolled overland flow and create sufficient channel capacity for safe disposal of storm waters. Without them farm runoff disposal systems, terraces, and diversion ditches could not be installed.

The annual reduction in flood damage from these measures in combination is expected to be $372,800.

One group of community channel improvements located in the San Timoteo drainage and the Santa Ana coastal plain are independent of other land-treatment measures. This group of channel improvements is expected to reduce flood damages by about $118,000 annually.

Sediment Damage Reductions.--Structures such as detention and retarding dams, levees, revetments, improved and lined channels, debris basins, and check dams have been used to retard and confine flood flows in both the San Gabriel and Santa Ana River watersheds. Large detention dams have

been constructed in the mountain canyons for flood control and water conservation. Heavy sediment-loaded discharges from the mountain tributaries will continue to deposit their loads in reservoirs and channels. Floodwater and debris flows from the smaller canyons discharging directly onto urban and agricultural lands will continue to cause trouble. Unconfined mountain channels above the protection works will continue to overflow, scour, and carry huge quantities of debris which will cause severe damage to all developments located in the area. The most serious and damaging problem, however, is the sedimentation of downstream flood-control and water-conservation works.

Although reservoirs, debris basins, and channels in the past have filled with sediment at alarming rates (Appendix 1, pages 22 and 23), the Corps of Engineers and the Los Angeles County Flood Control District have indicated that this debris can be handled satisfactorily. The methods proposed are: (a) sluicing from one reservoir to another until sediments reach improved channels where flood discharges can carry the eroded material to the ocean; (b) by provision of ample dead storage to collect debris for the designed life of the reservoir; or (c) the sale of deposited sediments to local sand and gravel companies now operating in the area. While these methods of handling debris do not attack the debris source areas, they do provide relatively inexpensive means of disposing of the sediments derived from the rapidly eroding mountain mass.

For purposes of this report it has been assumed that 50 percent of all debris in reservoirs could be sluiced at a cost of about 4 cents per cubic yard. 1/ Debris basins were assumed to require cleaning when 25 percent of the design capacity has been lost. Cleaning cost of debris basins was assumed to be $1.00 per cubic yard, based on such costs over the past 10-year period. Deposition in unimproved channels, urban, and agricultural properties was assumed to cost about $0.50 per cubic yard for removal.

Total annual sediment damage reductions were estimated to be $156,700, derived as follows:

San Gabriel Reservoir No. 1--According to Los Angeles County Flood Control District, the remaining 45,000 acre-feet of storage in this reservoir have been allocated to two uses--water conservation, 10,000 acre-feet; and flood control, 35,000 acre-feet. Sedimentation of the reservoir will use the water conservation storage first. The estimated benefit due to reduction in the sedimentation rate was computed as follows:

1/ Based on cost estimates furnished by the Los Angeles County Flood Control District.

Rate of deposition without program 2/	354 acre-feet
Rate of deposition with program 2/	305 acre-feet
Life of 10,000 acre-feet storage without program	28 years
Life of 10,000 acre-feet storage with program	33 years
Value of acre-foot of water 3/	\$20
Value of water-conservation storage	\$200,000
Service loss without program (200,000 ÷ 28) x present value of a decreasing annuity at 27(301.43957)	\$2,153,141
Service loss with program (200,000 ÷ 33) x present value of a decreasing annuity at 32(406.03288)	\$2,460,559
Difference	\$307,500
Interest rate	.025
Water conservation benefit (307,500 x .025)	\$7,688

After the 10,000 acre-feet of water conservation storage is lost, then the remaining 35,000 acre-feet reserved for flood control will start to be depleted.

Flood control storage life without program	99 years
Flood control storage life with program	115 years
Replacement cost of storage	\$20,090,000
Average annual damage without program 20,090,000 x .0023751	\$47,716
Average annual damage with program 20,090,000 x .0011655	\$23,415
Average annual benefit	\$24,301

Since sluicing of reservoir deposits will be essential a further saving will be effected:

Sluicing cost without program 354 acre feet x \$64 (or \$.04 per cu.yd.)	\$22,656
Sluicing cost with program 305 acre feet x \$64	\$19,520
Savings	\$3,136

2/ Assumes 50 percent of deposits can be sluiced. Estimated total rate without program 709 acre-feet; with program 611 acre-feet.

3/ Based on sale price of alternate source, Colorado River.

Value of reduced deposition in other reservoirs in the watershed was computed in the same manner, assuming 50 percent of the deposits could be sluiced at an average cost of about 4 cents per cubic yard. Benefits from six additional reservoirs are summarized as follows:

Reservoir	Average annual benefit
San Gabriel No. 2	\$13,200
Morris	1,430
Big Dalton	1,460
San Dimas	2,260
Live Oak	1,370
Thompson	620
Total	\$20,340

Benefits due to reduced sedimentation in authorized Corps of Engineers' debris basins were computed as follows:

Little Dalton Debris Basin:

Assumed design capacity 4/	330,000 cu. yd.
Average annual rate of deposition without program	10,395 cu. yd.
Cleaning required every 8 years 5/ at	\$1.00 per cu. yd.
Average annual cleaning cost $\left(\frac{10,395 \times 1.00}{8}\right)$	\$1,299
Average annual rate of deposition with program	9,339 cu. yd.
Cleaning required every 9 years at	\$1.00 per cu. yd.
Average annual cleaning cost $\left(\frac{9,339 \times 1.00}{9}\right)$	\$1,038
Savings	\$261

Big Dalton Debris Basin:

Assumed design capacity 4/	450,000 cu. yd.
Average annual rate of deposition without program	112,500 cu. yd.
Cleaning required every 9 years at	\$1.00 per cu. yd.
Average annual cleaning cost $\left(\frac{112,500 \times 1.00}{9}\right)$	\$12,500
Average annual rate of deposition with program	109,600 cu. yd.
Cleaning required every 11 years at	\$1.00 per cu. yd.
Average annual cleaning cost $\left(\frac{109,600 \times 1.00}{11}\right)$	\$9,964
Savings	\$2,540

4/ Based on information from Corps of Engineers, Los Angeles District, using 100,000 cubic yards per square mile rate.

5/ Corps of Engineers estimates that 25 percent of capacity can be lost before basins are cleaned.

Deposition in a number of unimproved channels, on agricultural and urban property was assumed to require removal based on past experience in this area. The cost of removal was assumed to be $0.50 per cubic yard on the average. The following areas were evaluated in this manner:

Drainage	Total annual deposition without program (Acre-feet)	Total annual deposition with program (Acre-feet)	Reduction (Ac.-feet)
Cucamonga	54.0	46.5	7.5
Deer	16.8	13.5	3.3
Day	29.0	23.9	5.1
San Sevine	5.4	4.5	0.9
East Etiwanda	8.8	7.4	1.4
City	39.4	29.3	10.1
Plunge	34.9	29.0	5.9
Upper Santa Ana	287.4	263.3	24.1
Wilson--Potato	21.1	19.0	4.1
Live Oak	20.1	16.2	3.9
West of Noble	2.2	2.2	.0
Edgar--Noble	30.8	24.9	5.9
Olive	5.0	4.0	1.0
San Timoteo	35.4	28.1	7.3
Reche	11.5	7.8	3.7
Potrero	142.7	96.0	46.7
Haggador--Tin Mine	5.2	4.5	0.7
Total reduction			131.6

Benefit due to reduced deposition:
131.6 x $807 (or $0.50 per cubic yard) $106,200

One of the many unevaluated benefits is the annual reduction of reservoir sedimentation in Whittier Narrows, La Brea, Carbon, Fullerton, and Prado reservoirs, which is estimated at 70,000 cubic yards. The reduction in the rate of soil removal from crop and range lands will be reflected in corresponding reductions in sediment damage to water spreading grounds, urban and rural improvements, streets, and irrigation facilities. Continued removal of the top soil by accelerated erosion will further reduce the productivity of the agricultural land. If this process is permitted to continue ultimate correction will become even more difficult and costly. Such reductions will extend the life of the agricultural enterprise and have a marked influence on the entire economy dependent upon it.

The sedimentation problem has not been adequately evaluated, largely due to a lack in physical, economic, and engineering data. Data on value

relations are needed. For instance: The amount of sediment removed from various reservoirs for sale as building materials compared to the quantity entering the reservoirs must be established. The long-term demands and sources of gravel and its value in relation to recreational values must be established. The question to be answered: Is the continuing deterioration of watershed land with its increased gravel production of greater value than improved watershed land with increased recreational use? There is need for value studies in time. For instance: At present large Federal flood-control structures and water conservation facilities are amortized over a 50-year period. Consideration must be given to the permanency of the community created or protected by these facilities. A comparison of the cost of improving the watershed and maintaining these facilities, thus creating a permanent community, must be made with the cost of temporary protection of water supply and ultimate abandonment of the community.

Treatment of floodwater and sediment source areas in the mountain or wild lands would do much to reduce sedimentation of downstream structures and channels. The Corps of Engineers and Los Angeles County Flood Control District are experimenting with ways and means of maintaining storage space in their flood-control structures. The present status of the District's work leads its engineers to believe that 50 to 75 percent of the sediment can be sluiced from their reservoirs at costs as low as 3 cents per cubic yard. The Corps of Engineers have already let contracts to gravel companies for excavating building material from Santa Fe Flood Control Basin at a profit to the United States Government.

Irrespective of the success of sluicing operations and excavations of material for use as aggregates there are reservoirs, debris basins, and channels in the watershed for which these methods will not be adequate. The wasteful use of the local "sweet" or high-quality water for sluicing may not be available or obtainable within economic costs; erosional debris deposited in the basin may not be suitable for use as building material or the location of the reservoir or basin may be such as to make sand and gravel extraction impracticable. Furthermore, the increasing pressures of the expanding population for land are making the use of land for storing waste material prohibitive without expensive hauling costs. Finally, the total quantity of material extracted from a basin may not be sufficient to maintain adequate flood-control capacity. Present experience makes it impossible to predict the location of these trouble units or their magnitude.

Agricultural Conservation Benefits.--These benefits amount to $1,366,400 for the accelerated portion of the proposed measures. The conservation benefits will be obtained by maintaining yields at present or above present levels on the land to which the intensified measures of the Department of Agriculture's conservation programs apply. Going programs will take care of 30 to 50 percent of this work during the next 20 years. The monetary appraisal of the conservation benefits in the Santa Ana watershed is made only for three major land uses--citrus, grain, and range. It includes land capability classes II, III, IV, VI, and VII. Basic assumptions made in these calculations and the estimated annual equivalent value of conservation benefits per acre are given in table 1.

Table 1.--Estimated value of conservation benefits, Santa Ana Watershed, (1946 prices)

Land use	Class	Present Production: Net return per box	Present Production: Boxes per acre	Without proposed program: Years until no net return		With proposed program: Years until no net return		Estimated annual equivalent value of conservation program per acre 1/	Total number of acres applied to
		Dollars	Number					Dollars	
Citrus									
Limited soil depth	II	.75	236	50		75		21.00	25,800
Limited soil depth	III & IV	.70	220	35		60		15.00	26,400
Limited soil depth	VI & VII	.65	220	30		50		14.25	3,300
		Present Production: Biannual yield	Present Production: Annual net per acre	Without proposed program: Years until: range use or grain yield	Without proposed program: Annual net per acre	With proposed program: Biannual yield	With proposed program: Annual net per acre		
		Bushels	Dollars		Dollars	Bushels	Dollars		
Grain									
Limited soil depth	II	25	9.00	50 yrs.	.50	25	9.00	3.80	23,100
Limited soil depth	III	20	3.50	30 yrs.	.25	20	3.50	1.95	34,200
Limited soil depth	IV & VI	12	0	20 yrs.	.20	Range	.75	.39	17,800
Unlimited soil depth	II	30	7.30	27 bu.	5.50	30	7.30	1.10	26,100
Unlimited soil depth	III	25	4.50	20 bu.	1.70	25	4.50	1.80	45,800
		Present capacity animal unit month		Years to	Animal unit month	Years to	Animal unit month		
		Acres			Acres		Acres		
Range	III	4		50	16	10	2	2/ .88	218,200
	IV	5		30	20	10	3	.48	38,100
	VI	7		20	28	10	4	.40	56,600
	VII	10		20	40	10	7	.23	28,300

1/ Difference between annual equivalent values of production with and without proposed program for perpetuity.
2/ Value per animal unit month = $3.00.

Conservation benefits in the San Gabriel watershed were based on the difference in net value of crop yields with and without the program, using 1947 prices.

These benefits were calculated for oranges, to represent citrus and avocados; walnuts, to represent deciduous fruits and nuts; tomatoes, to represent truck crops; grain-hay, to represent all hay and cereals; and grazing land to represent land retired from crop use.

It is expected that the proposed measures will maintain present yields. Without these measures orange yields are expected to decline between 78 and 137 boxes an acre in 50 years, depending on the class of land on which they are grown.

On walnuts the yield decline in 50 years is estimated to be about 300 pounds an acre. The yield decline for grain-hay in 50 years would vary between .50 ton and .87 ton. Tomato yields were estimated to decline about 5 tons an acre in 50 years.

Prices used in these calculations and the value of maintained yields credited as a benefit to farm-land treatment are given in table 2.

The decline in yields of citrus crops with resultant decline in gross and net income is based on an analysis of records on yields by land capability classes, age of groves, and management studies. Such records included growers' records, 1946 citrus management studies, University of California Citrus Enterprise efficiency studies, 1944-45-46 annual agricultural crop reports for San Bernardino County, and Soil Conservation Service farm plans. These analyses indicate a correlation of yield and land capability class. Field examination disclosed soil loss from erosion, and cultural deterioration with subsequent lowering of production.

The decline in net income was derived in the following manner. All fixed costs (cultivation, spraying, taxes, etc.) remain nearly constant as long as the grove is maintained. Therefore, the net declines at a more rapid rate than gross. Farm budgets indicate that the net benefits of maintaining yields results in a net gain of approximately 60 percent of the gross difference in income. Only 20 percent of the increased gross income is required for increased operating cost.

Table 2.--Basis for benefits from crop- and range-land treatment due to maintained yields: San Gabriel watershed (1947 prices)

Crop	Unit	Unit price	Benefit as percent of maintained yield
		Dollars	Percent
Citrus	Packed box	1.77	80
Walnut	Pounds	.388	80
Baled grain hay	Ton	24.40	80
Tomatoes	Ton	29.20	67
Grazing	Animal unit year	25.00	67

The total of all evaluated benefits from the crop- and range-land measures including community channel improvement is $1,962,300 a year.

Other Benefits

Reduced Fire Suppression Costs.--The intensified fire-control program will reduce the total cost of suppressing wild land fires. This will be accomplished by a reduction in the average annual area burned. Better detection of fires and more rapid attack will reduce the number of acres burned by individual fires. The calculated total expected average annual reduction in fire suppression costs is $77,200. Of this total, $59,200 is expected to accrue in the Santa Ana drainage and $18,000 in the San Gabriel watershed.

Reduced Road Maintenance Costs.--Road maintenance costs in areas burned by fire are above normal for several years following a fire. With a reduction in area burned there would be a reduction in road maintenance costs. The calculation of reduction in road maintenance cost expected to result from intensified fire control was based on studies made in the San Gabriel River watershed. In that portion of the report area, road maintenance records showed that fires caused increased maintenance costs for affected roads for about four years following fires. Based upon these records and the frequency and size of storms expected in the four-year period, it was calculated that the increased maintenance costs would be $3,758 per mile for minor roads and $22,170 for major roads, per year. These increased maintenance costs were revised to 1946 and 1947 price levels. The minor and major road increased maintenance cost per mile adjusted to 1946 price levels for the Santa Ana drainage was $5,374 and $31,703 respectively. For the San Gabriel (1947 price level) the adjusted minor road maintenance cost per mile is $6,426, and $37,910 for the major roads.

Data on the Forest Service road system show there are a total of 1,172 miles of minor roads in the National Forests. In addition, 75 miles of major roads are so located that increased maintenance would occur if the section of the watershed in which they are located would be burned. Roads outside the National Forest were not included because it was considered that, in general, this was the area of rugged relief such that denudation by fire would cause increased debris movement and additional maintenance work. A few miles of private and county roads within the National Forests but not part of the Forest Service network were also included as minor roads.

Of the total mileage of roads in the National Forest area used in the study, it was estimated that 70 percent of the minor roads and 75 miles of major roads, depending on location, would be likely to incur increased maintenance costs due to fires. Fire-control studies have shown that the probable average annual rate of burn in the National Forest portion of the report area in the future without an intensified control plan would be 2.85 percent. The recommended program is expected to hold the average annual burned area to 0.2 percent. This percentage reduction in area of fires was applied to the road mileages

discussed above with the result that expected increased maintenance costs would be eliminated on 21.73 miles of minor roads and 1.98 miles of major roads annually. Thus within the Santa Ana drainage, the expected benefit is $138,000, while in the San Gabriel it is $49,600. The total benefit is $187,600. There would also be a similar reduction in expected fire-caused increase in maintenance and upkeep of other utility lines such as railroads telephone and telegraph lines, power transmission lines, aqueducts, water, gas , and oil pipe lines, etc., but data are not available to permit monetary evaluation.

Reduced Property Loss by Fire.--A reduction in area burned will result in a reduction in property damage by fires. Fires destroy range forage, hay, grain, fences, bridges, buildings, and utilities.

From records of the U. S. Forest Service it is estimated that the average property loss from fire in the National Forest portion of the report area would be $7.70 per acre, based on 1948 prices. Corrected to 1946 and 1947 prices this becomes $5.77 and $6.47 respectively. For the portion of the wild land outside the National Forests the per acre property loss, according to California Division of Forestry records, is $3.00 per acre, based on 1946 prices. This becomes $2.52 per acre average loss, based on 1947 prices. For the Santa Ana watershed the total average annual reduction in property loss expected is $116,300. For the San Gabriel waterhsed it is $34,500.

Program Costs and Cost Allocation

The estimated installation cost for the crop and range-land measures is $26,812,400; annual operation, maintenance, and replacement costs are about $514,500. Community channels are the major installation expense estimated at $23,791,700; all other crop and range-land measures cost about $3,020,700. The cost for technical services, educational assistance, and administration of direct aids to farmers in installing measures on their land is included in these cost figures.

The estimated installation cost of the wild-land program of intensified fire control, acquisition, and road slope stabilization total $2,672,200 for the San Gabriel and $3,071,900 for the Santa Ana watershed. For these wild-land programs for both watersheds the annual operation and maintenance cost is $413,000.

The distribution of costs is shown in tables 3, 4, 5, and 6.

Table 3.--Distribution of installation costs by sources of funds, recommended remedial program, Santa Ana watershed (1946 prices)

Measures	Federal	Other public	Private	Total
	Dollars	Dollars	Dollars	Dollars
Intensified fire control	1,408,600	85,500	--	1,494,100
Road slope stabilization	646,200	412,400	19,200	1,077,800
Community channels	8,378,200	1,883,000	--	10,261,200
Farm runoff disposal	250,400	--	200,000	450,400
Terraces and diversion ditches	497,000	--	188,700	685,700
Range improvement	239,200	--	139,000	378,200
Grass seeding	74,900	--	82,100	157,000
Acquisition	500,000	--	--	500,000
Total	11,994,500	2,380,900	629,000	15,004,400

Table 4.--Distribution of annual operation, maintenance, and replacement costs by source of funds, recommended remedial program, Santa Ana watershed (1946 prices)

Measures	Federal	Other public	Private	Total
	Dollars	Dollars	Dollars	Dollars
Intensified fire control	223,400	47,000	--	270,400
Road slope stabilization	6,500	4,100	200	10,800
Community channels	--	253,700	--	253,700
Farm runoff disposal	--	--	16,500	16,500
Terraces and diversion ditches	--	--	31,500	31,500
Range improvement	--	--	18,000	18,000
Total	229,900	304,800	66,200	600,900

Table 5.--Distribution of installation costs by ted Long- funds, recommended remedial program, San Gabriel wat--shed (1947 prices)

Measures	Federal	Other public	Private	Total
	Dollars	Dollars	Dollars	Dollars
Intensified fire control	965,200	102,100	--	1,067,300
Road slope stabilization	1,132,400	472,500	--	1,604,900
Community channels	10,095,500	3,435,000	--	13,530,500
Farm runoff disposal	514,300	--	497,000	1,011,300
Terraces and diversion ditches	63,700	--	26,500	90,200
Range improvement	57,600	--	37,000	94,600
Grass seeding	66,900	--	86,400	153,300
Total	12,895,600	4,009,600	646,900	17,552,100

Table 6.--Distribution of annual operation, maintenance, and replacement costs by source of funds, recommended remedial program, San Gabriel watershed (1947 prices)

Measures	Federal	Other public	Private	Total
	Dollars	Dollars	Dollars	Dollars
Intensified fire control	96,300	18,900	--	115,200
Road slope stabilization	6,600	10,000	--	16,600
Community channels	--	141,000	--	141,000
Farm runoff disposal	--	--	41,000	41,000
Terraces and diversion ditches	--	--	1,800	1,800
Range improvement	--	--	11,000	11,000
Total	102,900	169,900	53,800	326,600

Benefits and Costs in Terms of Projected Long-Term Prices

Benefits and costs of the measures for the San Gabriel drainage are based on the 1947 price level and those of the Santa Ana drainage on prices prevailing in 1946. To express both on a comparable basis and at the same time on prices that may be expected to prevail over a longer period of time, the 1946 and 1947 prices were converted to projected long-term prices proposed by the Federal Inter-Agency River Basin Committee. The following indexes were used for this conversion:

	1946	1947
Citrus	.89	.89
Truck crops	--	.84
Nuts	--	.85
Grain	.73	--
Grain-hay	--	.80
Cattle	1.17	.92
Construction cost	1.23	1.03
Prices paid by farmers	1.04	.90

The average annual equivalent costs of the measures is obtained by taking 2-1/2 percent interest on installation cost to be borne by Federal and other public agencies and 4 percent on the cost to be borne by private individuals, and adding this to the average annual operation, maintenance, and replacement cost. The average annual equivalent cost, in terms of projected long-term prices, is $1,916,900, as shown below and in table 7.

Interest on investment	$ 852,230
Operation, maintenance, and replacement	1,064,670
Average annual equivalent cost	$ 1,916,900

This includes the cost for independent channel developments for which the costs separately are $107,500.

Interest on installation	$ 50,300
Operation, maintenance, and replacement	57,200
Average annual equivalent cost	$ 107,500

Based on long-range price projections the average annual benefits total $2,361,900. Of this total amount, $646,400 is attributable to flood damage reduction and sediment damage reduction. Conservation benefits total $1,217,200 and other incidental benefits make up the balance. See table 8.

The benefit cost ratio, using 1946-47 prices, is 1.38:1.00, and 1.23:1.00, using projected long-term prices.

Table 7.--Combined San Gabriel-Santa Ana installation and operation, maintenance and replacement costs of the recommended program

Measures	Instal- lation	Operation, maintenance, and replacement	(1946-47 costs) average annual	Normal price long-range average annual cost
	Dollars	Dollars	Dollars	Dollars
Fire control	2,561,400	385,600	449,700	479,200
Road slope stabilization	2,682,700	27,400	94,700	106,200
Community channels	22,156,700	348,200	902,200	1,013,900
Community channels, independent	1,635,000	46,500	87,400	107,500
Farm runoff disposal	1,461,700	57,500	104,500	113,800
Terracing	775,900	33,300	56,000	58,200
Range improvement	472,800	29,000	43,400	15,600
Grass seeding	310,300	---	10,300	10,000
Land acquisition	500,000	--	12,500	12,500
Total	32,556,500	927,500	1,760,700	1,916,900

Table 8.--Combined San Gabriel-Santa Ana benefits

Measures	(1946-47 costs) average annual	Normal price long-range average annual benefits
	Dollars	Dollars
Flood damage reductions	490,800	463,800
Sediment damage reduction	156,700	182,600
Water conservation	7,700	7,700
Conservation benefits (agricultural land)	1,366,400	1,217,200
Reduced fire suppression costs	77,200	91,300
Reduced road maintenance costs	187,600	220,800
Reduced property loss by fire	150,800	178,500
Total	2,437,200	2,361,900

Flood damage reduction from the independent channel improvements which are included in the over-all benefits are $114,500.